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Water Balance and Economic Analyses of Reduced Pressure/ Conservation Tillage Systems for Irrigated Corn Production

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WATER BALANCE AND ECONOMIC ANALYSES OF REDUCED PRESSURE/CONSERVATION TILLAGE SYSTEMS FOR IRRIGATED CORN PRODUCTION

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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ABSTRACT

Water balance and economic analyses of a five-year tillage and irrigation study in South Dakota were performed. Three primary tillage, pre-plant, operations (Plow, Disk and Till-Plant), two secondary tillage, post-emergence, operations (Inter-Row Tillage and a Control), and four sprinklers operating at pressures of 41 to 344 kPa were studied. Surface runoff, soil water storage and evapotranspiration values were 8, -8 and 100% of total water input values during a study period from late June to mid-August. Evapotranspiration values averaged 7.1 mm/day for the study period. Deep percolation loss was calculated to be zero. The Inter-Row Tillage treatment produced less surface runoff and more soil water storage than the Control treatment.

Pumping and tillage costs were used in the economic analysis, with pumping cost being the dominant parameter. The Disk primary tillage treatment and Inter-Row secondary tillage treatment were economically superior to the other tillage treatments.

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INTRODUCTION

Energy savings associated with low pressure sprinkler irrigation have made conversion to reduced pressure systems an attractive alternative to irrigators in recent years. A main drawback of reduced pressure systems is the associated increase in application intensity, often producing increased surface runoff and erosion and decreased application uniformities. Soils with crusting tendencies can aggravate the surface runoff problem caused by low pressure sprinklers (Gilley and Mielke, 1980). The presence of decreased uniformity and/or increased runoff often results in lower yields and the need for extra irrigation water. These factors can outweigh the benefits of decreased pumping costs.

Recent attention has been focused on the possibility of decreasing surface runoff from reduced pressure irrigation with changes in tillage practices (Gilley et al., 1983 and DeBoer and Beck, 1983). A five-year study was initiated in 1981 in north central South Dakota (near Gettysburg) to determine the effects of conservation tillage on reduced pressure irrigated corn production. The research was supervised by Dr. Darrell DeBoer and Dr. Dwayne Beck of South Dakota State University. Conservation tillage practices included both primary (pre-plant) and secondary (post-emergence) tillage treatments. Several reduced pressure sprinklers were also used in the study.

One of the research goals was to obtain field data concerning the fate of water inputs for irrigated corn in central South Dakota. Of particular interest was daily evapotranspiration demand, because it is a primary parameter used in irrigation scheduling procedures. Field evapotranspiration data are limited for South Dakota conditions. Another research goal was to use the water data set as a basis for economic evaluation of the tillage/sprinkler combinations and to determine feasible management alternatives for irrigators.

OBJECTIVES

Objectives of this thesis are:

1. Conduct a water balance analysis of the Gettysburg field research site and statistically analyze the water balance variables to identify differences among primary tillage practices, secondary tillage practices and/or sprinklers.
2. Determine average daily evapotranspiration for corn in central South Dakota from the water balance analysis.
3. Develop a computer model to assist in the economic analysis of irrigation system and/or tillage practice modifications.
4. Use the computer model to determine economic differences among the various conservation tillage/-sprinkler device combinations.

One type of primary tillage, two types of secondary tillage and four sprinkler types were used on the sprinkler area. Disking was the primary tillage operation. Secondary tillage was performed when the crop was in the six to eight leaf stage and consisted of a shallow cultivation (Control) or inter-row tillage (IRT) plus a shallow cultivation. IRT was used to create a vertical channel for infiltration and involved operating a ripper or parabolic-shanked implement at a depth of 250 to 300 mm between corn rows immediately after a shallow cultivation. Numerous sprinkler devices were used during the study. Four chosen for analysis in this thesis were low angle impact at 344 kPa (I-344), low angle impact at 172 kPa (I-172), 360 degree spray nozzles with serrated, concave downward spray plates at 103 kPa (S-103), and 360 degree inverted spray nozzles on drop tubes at 41 kPa (D-41). These application packages provided a large range of operating pressures, wetted diameters, drop sizes and application intensities.

Three types of primary tillage, two types of secondary tillage and a single sprinkler device were used on the primary tillage area. Primary tillage operations were Plowing, Disking and Till-Planting. Secondary tillage consisted of IRT and Control methods. I-172 sprinklers were used to irrigate the primary tillage area from 1982 through 1985. A 41 kPa spray nozzle (S-41) was used in 1981.

All primary tillage was performed in the spring since the research site was winter grazed. Planting date, population and fertilizer and herbicide application were consistent for all plots. Corn was planted in late April or early May at a rate of 75,360 to 88,950 kernels/ha. Row width was 0.91 m in 1981 and 1982 and 0.76 m for the remainder of the study. Nitrogen fertilizer was applied at a rate of 300 kg/ha for a 12,550 kg/ha yield goal. Approximatley 85% of the nitrogen was applied before planting with the remainder applied later in the season through the irrigation system. Fifty six L/ha of liquid 10-34-0 was used in 1981 and 56 kg/ha of dry 18-46-0 was used the remaining years as a starter fertilizer. Combinations of Lasso and Atrazine or Bladex and Atrazine were used for weed control.

WATER BALANCE ANALYSIS

INTRODUCTION

A water balance is a detailed statement of the law of conservation of mass. Water distribution was analyzed using:

$$I + P = R \pm DP \pm GS + ET \text{ --------------------------- } (1)$$

where

- I = irrigation water reaching crop canopy
- P = precipitation
- R = runoff
- DP = deep percolation
- GS = ground storage (positive for increases; negative for decreases)
- ET = evapotranspiration

All variables have units of depth.

The crop canopy was used as the starting point of the analysis because complete measurements of spray loss and depth of water leaving the irrigation system were not available. Plant interception was not considered in the analysis.

LITERATURE REVIEW

In order to make this literature review more pertinent to the research project, only studies concerning corn production on soils and ground slopes similar to those at the research site will be reviewed.

Runoff

Two main methods are used to measure runoff in field experiments. The first involves collecting and storing the entire runoff volume for measurement. This approach is obviously limited to small runoff volumes. The second method measures runoff intensity and records it in the form of a hydrograph. The latter approach requires somewhat more instrumentation but allows measurement of large runoff volumes and provides a record of both runoff intensity versus time and total runoff volume.

Runoff depth is dependant upon variables such as cropping practice, tillage practice, soil type, surface roughness, soil slope, and water application intensity and duration. The majority of research cited investigated the effect of tillage practice and/or residue cover on runoff depth, while one study analyzed the joint effect of tillage and sprinkler type. Generally, decreased amounts of tillage and/or increased residue cover reduced runoff. Also, contour farming produced less runoff than up-and-down slope tillage. Secondary tillage was particularly effective in reducing runoff in soils with a crusting tendency. A decrease in sprinkler pressure tended to increase runoff, while for the same low operating pressure, impact sprinklers produced considerably less runoff than spray nozzles.

Mannering et al. (1966) studied the effect of various tillage practices on runoff under simulated rainfall conditions. The tillage practices consisted of conventional tillage-cultivation, minimum tillage-cultivation and minimum tillage-no cultivation. Water was applied for 60 min at a rate of 66 mm/h, followed the next day by two 30 min rains, separated by 15 min, at the same intensity. The minimum tillage-no cultivation practice produced the most runoff (67%), followed by conventional tillage-cultivation (56%) and minimum tillage-cultivation (40%). The authors concluded that cultivating to destroy surface crusts was very beneficial in reducing runoff.

The effect of tillage practices on runoff in eastern South Dakota under natural rainfall conditions was studied by Onstad (1972). Conventional, mulched, till-planted up and down the slope, and till-planted on the contour were the tillage practices studied. Rainfall and runoff were measured from April 1 to October 31 during the six-year study. Total rainfall varied from 324 to 513 mm and averaged 419 mm. For every year of the study, conventional tillage produced the most runoff, followed by mulch, till-plant up and down the slope and till-plant on the contour. Average runoff amounts over the six-year period for the above-mentioned practices were 50, 29, 24 and 10 mm, respectively.

Baker et al. (1978) measured runoff losses for six tillage systems under simulated rainfall conditions. The tillage practices produced residue covers ranging from 4 to 63%. Simulated rainfall was applied as a 1.4 h rain at 63.5 mm/h in the afternoon, followed the next morning by a one hour rain at 63.5 mm/h and a 0.5 h rain at 127 mm/h. Total runoff was 168 mm under 4% cover, 156 mm under 21% cover and 113 mm under both 31 and 63% cover. These results indicate an inverse relationship between runoff depth and percent residue cover up to approximately 30%.

The effects of residue weight on runoff losses under simulated rainfall conditions was analyzed in a separate study by Baker et at. (1982). Residue amounts varied from zero to 1500 kg/ha and water was applied at a rate of 63.5 mm/h for a two-hour period. Total runoff was 62.8 mm for no residue, 51.9 mm for 375 kg/ha of residue, 43.5 mm for 750 kg/ha of residue and 17.8 mm for 1500 kg/ha of residue, showing an inverse relationship between residue mass and runoff depth.

McGregor and Greer (1982) measured runoff for conventional, reduced and no-till tillage practices under natural rainfall conditions in Mississippi. Rainfall averaged 1239 mm for the three-year study. Conventional tillage produced the most runoff (30%), followed by no-till (26.5%) and reduced tillage (16.7%).

Gilley et al. (1986) measured runoff from various sprinkler/tillage combinations in a four-year Nebraska study. The sprinkler devices consisted of high-pressure (410 kPa) impact, low-pressure (140 kPa) impact and low-pressure (140 kPa) spray nozzles. The tillage systems studied were till-plant (shred stalks in spring, plant, cultivate), disk (tandem disk twice, plant, cultivate) and chisel (till-plant plus chisel treatment after cultivation). Water was applied with a center-pivot irrigation system at an average depth of 36.2, 34.8 and 35.6 mm for the high-pressure impact, low-pressure impact and low-pressure spray nozzles, respectively. For the four-year study, high-pressure impact sprinklers had the least runoff (0.7%), followed by low-pressure impact (0.9%) and low-pressure spray (4.9%). Also, the chisel tillage system produced the lowest average runoff (0.3%), followed by till-plant (2.6%) and disk (3.6%).

Runoff under conventional tillage practices for varying application depths in Colorado was analyzed by

Kincaid et al. (1979). A center pivot irrigation system applied 715, 770 and 860 mm of water, equaling 100, 105 and 115% of the calculated evapotranspiration requirement. No information was given concerning application intensity or application depth per irrigation. Runoff losses were less than three percent for the three application depths studied.

Deep Percolation

Deep percolation is downward water flow across the lower boundary of the root zone, producing inefficient application and subsequent pumping cost increases. Downward flow may be necessary, however, if salt leaching is required. Upward flow from shallow watertables is also possible and is obviously beneficial to an irrigator because of the associated reduction in pumping costs.

The most direct method of determining percolation is measurement of flow from drain lines when a water table is present. The simplicity of this approach is countered by the cost of drain line installation and frequent absence of a water table. A common approach is in situ flux measurement using tensiometers at different depths. Soil water flux is obtained as the product of potential gradient, measured by the tensiometers, and the unsaturated hydraulic conductivity of the soil. A drawback of this technique is that accurate determination of unsaturated hydraulic conductivity as a function of water content or pressure head is very difficult to obtain. Deep percolation is often measured using a water balance approach where percolation equals total inputs minus runoff and evapotranspiration. This method is very simple but the change in ground storage is seldom considered and measurement errors of the other water balance components may mask the magnitude of the deep percolation variable.

Groundwater movement in the unsaturated zone is a complex process dependent upon many soil parameters. Difficulties in determining these parameters and relating them to groundwater flow have hindered accurate field measurement of deep percolation. An important variable in determining deep percolation is the soil depth at which water is assumed to be lost to the crop. Soil properties and crop type are important variables in determining this depth. Quite frequently the depth at which deep drainage is assumed to occur is arbitrarily chosen as the lowest depth at which soil water contents are measured. Research studies of deep percolation under irrigated corn production are quite limited and very site specific. Deep percolation was 1.0 and 12% in the two studies cited.

Kincaid et al. (1979) measured leaching fraction (deep percolation divided by irrigation depth) under varying application depths (100, 105 and 115% of calculated evapotranspiration requirement) using vacuum extractors at 1.07 m depths. The analysis period was from May 4 to October 6 and the total application depths corresponding to the above-mentioned amounts were 715, 770 and 860 mm, respectively. Leaching fraction varied from a low of 0.01 for the 100% application to a maximum of 0.05 for the 115% application depth. The soil's volumetric water capacity was 26%.

Hanna et al. (1983) estimated deep percolation using a water balance equation for ground slopes of two and four percent in a Nebraska study. Water input, runoff and soil moisture difference were measured, and evapotranspiration was calculated using mean daily temperatures. Total water input of 610 mm from June 16 to September 4 resulted in deep percolation of 73 mm (12%) under two percent slopes and 40 mm (7%) under four percent slopes. Deep drainage was considered to be any water movement below the 1.37 m depth.

Ground Storage

Ground storage is the difference in root zone moisture content over a particular time period. Ground storage is a significant and dynamic component of the water balance for a relatively short period of time, such as a day or a week. When an entire irrigation season is considered, however, ground storage is usually assumed negligible. This assumption can lead to significant errors in some situations.

Ground storage can be obtained directly using a neutron probe to measure moisture content. Another common procedure is to measure matric potential with tensiometers and determine moisture content from the soil moisture release curve.

Ground storage studies are very site-specific because the amount of water held in the soil is dependent upon soil texture and porosity. The depth of the assumed profile is important and dependant upon the type of crop under consideration. Another key factor is the amount of water available for crop use. Due to the importance of available water, only studies under irrigated or well-watered conditions were considered in this literature review. Most studies investigated the effect of application frequency and/or depth on soil moisture, while one study analyzed the effect of ground slope. No significant ground storage differences were produced by varying application frequency, application depth per irrigation or ground slope. Total application depths of less than the calculated crop need had a much larger effect on soil moisture than did depths in excess of crop need.

Fischbach and Somerhalder (1974) investigated the effect of application frequency and depth on soil moisture content. Two application frequencies (3.5 and 7.0 days) and four application depths (33, 50, 75 and 100% of the calculated peak daily use rate) were studied. The 0-1.5 m soil profile was at field capacity on June 14 and was monitored until September 20. Rainfall during this period equaled 240 mm and total water input varied from 396 to 602 mm. The different application frequencies had no significant effect on soil moisture content, while decreasing application depth increased soil water extraction. The depth of water extraction over the analysis period for the various application rates was: 0 mm (100% rate); 13 mm (75% rate); 44 mm (50% rate); and 178 mm (33% rate).

DeBoer et al. (1977), in a three-year South Dakota study, analyzed the soil moisture change in a 0.9 m profile under varying application depths (25, 50 and 75 mm) per irrigation. The average period of analysis was from July 7 to August 31, and the average total water input during this period was 286 mm. No significant soil moisture difference was found among the application depths. The overall average moisture change was a depletion of 12 mm.

Kincaid et al. (1979) studied the effect of total application depth on soil water content in Colorado. Application depths of 100, 105 and 115% of the calculated evapotranspiration requirement were applied from May 4 to October 6 with a center pivot irrigation system. The depths associated with these percentages were 715 mm, 770 mm and 860 mm, respectively. A positive soil moisture change of one percent by volume was found for the 100 and 105% application rates, while a positive change of two percent was found for the 115% rate. The volumetric water capacity of the soil was 26% and water content was analyzed to a depth of 1.2 m.

Hanna et al. (1983) analyzed the effect of ground slope on soil moisture content under a center pivot irrigation system in Nebraska. The period of analysis was from June 16 to September 4, and the total water input during that time was 610 mm. Moisture loss in the 0-1.37 m profile was four millimeters for a two percent slope and three millimeters for a four percent slope. The soil moisture content did not seem to be affected by slope, since slope increased runoff and reduced internal drainage at approximately the same rate.

Evapotranspiration

Evapotranspiration (ET) is comprised of evaporation from soil and plant surfaces plus transpiration through plant tissues. These variables are usually considered together because evaporation and transpiration are difficult to separate under field conditions.

Direct measurement of ET is normally accomplished with weighing lysimeters. Lysimeters, however, can be expensive to install and are normally limited in size. Consequently, direct field measurement of ET is not common. Evapotranspiration is often obtained indirectly using the water balance equation and field measurements. Since assumptions are commonly made concerning one or more equation variable, the accuracy of this approach is dependent upon the accuracy of the assumptions and the data.

Evapotranspiration is dependent upon climatic conditions, growth stage, water input, and plant population. As in the ground storage literature review, only research under irrigated or well-watered conditions will be cited. Since study locations and durations varied greatly, it is difficult to make comparisons among studies. However, the studies showed that evapotranspiration was not affected by application depth per irrigation but was affected by primary tillage. Corn under conventional tillage transpired more than no-tillage corn.

Stewart et al. (1975) used lysimeters to measure corn ET during a two-year study in California. Evapotranspiration during an entire growing season under well-watered conditions averaged 630 mm. The plant population was 62,000 plants/ha.

Rosenthal et al. (1977) used a water balance approach to measure ET for irrigated corn in Kansas. Evapotranspiration from May 1 to September 23 averaged 620 mm with drainage assumed negligible. Corn was planted at a rate of 70,000 plants/ha.

DeBoer et al. (1977) studied the effects of application depth per irrigation on evapotranspiration during a three-year study in South Dakota. A water balance equation was used to measure ET with drainage assumed negligible. The average period of analysis was from July 7 to August 31, and the overall average evapotranspiration during this 55-day period was 300 mm. Application depth per irrigation had no effect on ET.

Phillips et al. (1980) compared no-tillage and conventional tillage for corn production in Kentucky. Evapotranspiration during a five month period during the growing season was 433 mm or 85 percent of water input for conventional tillage and 348 mm or 68.5 percent of input for no-tillage. Corn transpired a minimum of 500 kg of water for each kilogram of dry matter produced. The technique used to measure ET was not stated.

Sternitzke and Elliott (1986) measured evapotranspiration from well-watered corn using a water balance approach. Research was conducted in Oklahoma during 1984 and 1985. Daily evapotranspiration in 1984 between June 14 and August 26 averaged 8.9 mm. Daily evapotranspiration in 1985 averaged 6.8 mm between July 12 and August 29. Planting population for both years was 64,000 plants/ha.

PROCEDURE

All water balance variables were analyzed for a period from crop cultivation or secondary tillage until late in the growing season (Table 1). Irrigation and precipitation occurred prior to the starting dates, but installation of data collection equipment was impossible due to secondary tillage requirements.

Table 1. Period of analysis for water balance.

Year	Study	Starting Date	Ending Date	Number Of Days
1981	Sprinkler	July 6	August 17	43
	Tillage	July 6	August 17	43
1982	Sprinkler	June 22	August 16	56
	Tillage	June 22	August 16	56
1983	Sprinkler	June 20	August 15	57
	Tillage	June 21	August 12	53
1984	Sprinkler	June 22	August 16	56
	Tillage	June 22	August 16	56
1985	Sprinkler	June 27	August 14	49
	Tillage	June 28	August 13	47
Ave.	Sprinkler	June 25	August 16	53
	Tillage	June 26	August 15	51

Irrigation, Precipitation

All water inputs were measured and recorded manually using one quart oil cans (7854 mm^2 area) in 1981 and 1982 and rectangular wedge-shaped raingages (3654 mm^2 area) in 1983, 1984 and 1985. Oil cans or raingages were at a height of two meters or the top of the canopy, whichever was higher. The numbers of oil cans or raingages used per plot for the various years were: 1981-27; 1982-5; 1983-5; 1984-5 and 1985-5.

Runoff

Irrigation runoff was measured using calibrated HS flumes and Stevens stage recorders. Runoff from an entire plot (6 row widths) was directed through a flume and the resulting hydrograph was integrated to determine runoff depth.

Precipitation runoff estimates were based upon experimental results at the research site (Moshref-Javadi, 1986) and a subjective comparison to measured irrigation runoff. Only three storms over the five-year period were assumed large enough to require runoff estimates. Specific data on precipitation events and the associated estimated runoff are listed in Appendix B.

Deep Percolation

Deep percolation was measured under selected sprinkler/tillage combinations during two irrigations in 1985. Eleven pairs of mercury gauge tensiometers were installed at 1.20 and 1.50 m to measure matric potential gradients. The tensiometers were located in Microdike and Control sprinkler plots under D-41 and I-172 application packages. Microdike plots contained 200-mm high dikes at two-meter spacings which eliminated runoff. It was believed the chosen sprinkler/tillage combinations would provide the greatest range of deep percolation conditions. Hourly measurements, taken after two irrigations in mid-August, were used to estimate the seasonal water loss due to deep percolation.

Deep percolation rate was calculated using Darcy's Law for vertical flow (Skaggs et al., 1983):

$$V = (-Ku * dh/dz) - Ku \quad \text{------------------------} (2)$$

where

V = Darcian velocity; mm/h

Ku = unsaturated hydraulic conductivity; mm/h

dh/dz = matric potential gradient; mm/mm

Unsaturated hydraulic conductivity was determined using the empirical relationships developed by Brooks and Corey (1964):

$$Ah^{-B} = (M-Mr)/(Ms-Mr) \quad \text{----------------------------} (3)$$

$$Ks = \frac{(9.72 * 10^{6}) * (Ms-Mr)^{2} * B^{2}}{(A)^{2/B} * (1+B) * (2+B)} \quad \text{--------------} (4)$$

$$Ku = Ks * [(M-Mr)/(Ms-Mr)]^{C} \quad \text{--------------------} (5)$$

$$C = (2+3B)/B \quad \text{------------------------------------} (6)$$

where

A = regression constant

h = matric potential; mm

B = regression constant

M = moisture content; mm^3/mm^3

Mr = residual moisture content; mm^3/mm^3

Ms = saturation moisture content; mm^3/mm^3

Ks = saturated hydraulic conductivity; mm/h

Ku = unsaturated hydraulic conductivity; mm/h

C = regression constant

Moisture release curve and saturation moisture content data were collected for the 1.30-1.40 m soil profile (Kohl, 1985). These data were substituted into Equation 3 and a linear regression was used to determine the regression constants Mr, A and B. Saturated hydraulic conductivity (Ks) was calculated using Equation 4. Equations 5 and 6 were used to determine unsaturated hydraulic conductivity (Ku) for Equation 2. Moisture content at a location was determined using Equation 3 and the average of the matric potential values at 1.20 and 1.50 m.

An estimate of the seasonal loss due to deep drainage was obtained by assuming that the average Darcian velocity was constant over an entire irrigation season (52 days). Since measurements were taken when deep percolation would be the greatest (after irrigations), this approach produced conservative values which should be higher than actual values.

Ground Storage

Ground storage was determined by calculating the volumetric water content difference between the beginning and end of an analysis period. A neutron probe was used to determine volumetric water content. Neutron readings were taken at 150 mm increments to a depth of 1.20 m at the center of each plot. Readings were equated to volumetric water content using a calibration curve developed from controlled field conditions.

Evapotranspiration

Evapotranspiration was the only variable not measured and was calculated using the water balance equation. Values of total and average daily evapotranspiration were determined.

Statistical Analysis

Data were evaluated using least-squares analysis of variance (Steel and Torrie, 1980) with the assistance of Dr. William Tucker, Professor/Experiment Station Statistician, South Dakota State University. The sprinkler study and primary tillage study were analyzed separately. Dependent variables were total input, total runoff, ground storage, total evapotranspiration and average daily evapotranspiration. Primary tillage, secondary tillage, sprinkler type and year were the independent variables considered. Data from the first year of the primary tillage study were omitted from analysis since the sprinkler (S-41) was not consistent with the remainder of the study. Statistical significance was assumed to occur at the five percent level.

RESULTS AND DISCUSSION

The results and discussion section will consist of three main parts. The first will present an analysis of the deep percolation variable of the water balance equation. This variable is considered first since it was found to be negligible and was consequently eliminated from further analysis. The second part will list overall values, in terms of depth and percent of total inputs, for the water balance variables. The final part will present a statistical analysis of individual water balance variables to identify differences among primary tillage practices, secondary tillage practices and/or sprinkler types.

Deep Percolation

Deep percolation during a projected 52-day period occurred only under the Dikes/D-41 combination for the two irrigation events monitored (Table 2). The Darcian velocities produced by the other tillage/sprinkler combinations were too small to account for even one millimeter of deep percolation over the assumed period. Deep percolation for the Dikes/D-41 combination ranged from one to ten millimeters and averaged four millimeters. Since these values were small compared to the magnitude of the other water balance variables, and since the calculation

Table 2. Average soil water Darcian velocities and deep percolation during projected (52-day) analysis period for the two monitored irrigation events.

Secondary Tillage	Sprinkler Type	Location In Plot[a]	Darcian Velocity (mm/h * 10^5)	Deep Percolation (mm)
8/13/85 Irrigation				
Dikes	I-172	Top	4.6	0
		Bottom	20.9	0
	D-41	Top	768.6	10
		Bottom	97.8	1
	D-41	Top	228.1	3
		Bottom	561.2	7
Control	I-172	Top	6.8	0
		Bottom	9.1	0
	D-41	Top	1.0	0
		Bottom	2.5	0
	D-41	Bottom	2.8	0
8/15/85 Irrigation				
Dikes	I-172	Top	8.7	0
		Bottom	27.3	0
	D-41	Top	282.9	4
		Bottom	61.6	1
	D-41	Top	125.0	2
		Bottom	164.8	2
Control	I-172	Top	6.1	0
		Bottom	7.8	0
	D-41	Top	-0.1	0
		Bottom	1.6	0
	D-41	Bottom	1.2	0

a The irrigation machine traveled from the top to the bottom of the plots. Runoff ran towards the bottom of the plots.

procedure produced a worst case scenario, deep percolation was assumed to be zero for all tillage/sprinkler combinations and was consequently eliminated from further analysis. Detailed deep percolation test data are listed in Appendix C.

Water Balance

The following data are overall average values for the five-year study. Specific research results for individual water balance variables, along with yearly water balance summaries, are tabulated in Appendix D.

Sprinkler Study. Total input during the five-year study averaged 378 mm, 79% due to irrigation and 21% due to precipitation (Table 3). Total runoff averaged 30 mm (8% of water inputs), ground storage was -19 mm (-5% of water inputs) and evapotranspiration equaled 366 mm (97% of water inputs). Since only one sprinkler (I-172) was used all five years of the study, the overall averages are based on different yearly combinations.

Primary Tillage Study. Total input in the primary tillage study averaged 381 mm (Table 4). Eighty-two percent of this input was irrigation and 18% was precipitation. Compared to the sprinkler study, primary tillage runoff was the same (30 mm or 8% of water inputs), ground storage (-35 mm or -9% of water inputs) was less and evapotranspiration (386 mm or 102% of water inputs) was larger. All averages are based on 1982-1985 data.

Table 3. Overall water balance summary for sprinkler study.

Primary Tillage	Secondary Tillage	Sprinkler Type	I	+ P	= R	+ GS	+ ET
			(mm)				
Disk	IRT	I-344a	231	92	6	0	316
		I-172b	299	79	10	- 4	372
		S-103c	319	67	10	- 5	381
		D-41d	350	72	28	- 9	404
Disk	Control	I-344a	231	92	28	-20	315
		I-172b	299	79	39	-26	365
		S-103c	319	67	59	-43	370
		D-41d	350	72	60	-45	407
Overall Variable Average			300	78	30	-19	366
			(% of I+P)				
Disk	IRT	I-344a	72	28	2	0	98
		I-172b	79	21	3	- 1	98
		S-103c	83	17	3	- 2	99
		D-41d	83	17	7	- 2	96
Disk	Control	I-344a	72	28	9	- 6	98
		I-172b	79	21	11	- 7	96
		S-103c	83	17	16	-12	96
		D-41d	83	17	14	-11	96
Overall Variable Average			79	21	8	- 5	97

a Based on 1981-1984 data.
b Based on 1981-1985 data.
c Based on 1982-1985 data.
d Based on 1983-1985 data.

Table 4. Overall water balance summary for primary tillage study.

Primary Tillage	Secondary Tillage	Sprinkler Type	I	+ P	= R	+ GS	+ ET
			Variables[a] (mm)				
Plow	IRT	I-172	314	67	23	-32	390
	Control	I-172	314	67	46	-63	398
Disk	IRT	I-172	314	67	8	- 7	380
	Control	I-172	314	67	31	-49	399
Till Plant	IRT	I-172	314	67	15	-18	384
	Control	I-172	314	67	55	-40	366
Overall Variable Average			314	67	30	-35	386
			(% of I+P)				
Plow	IRT	I-172	82	18	6	- 8	102
	Control	I-172	82	18	12	-18	105
Disk	IRT	I-172	82	18	2	- 2	100
	Control	I-172	82	18	9	-13	105
Till Plant	IRT	I-172	82	18	4	- 4	101
	Control	I-172	82	18	15	-11	96
Overall Variable Average			82	18	8	- 9	102

a All values based on 1982-1985 data.

Statistical Analysis

Statistical analysis summaries for individual water balance variables and associated least-squares means are tabulated in this section. Abbreviations used in the following tables are: Y = year, PT = primary tillage, ST = secondary tillage and SP = sprinkler. Throughout this section two-way and three-way interactions are represented by Roman numerals for reasons of brevity. Also, the word "mean" will always refer to a least-squares mean. In several instances, individual variables and/or interactions in the sprinkler study showed significance, but least-squares means were inestimable. This occurred because three of the four sprinklers were not used every year of the study, resulting in missing data. In the following discussion statistical significance occurs at the 5% level. If statistical significance is not explicitly stated, any comments made cannot be statistically justified. A complete listing of the raw data used to perform the least-squares analysis of variance is given in Appendix E.

Total Input (Sprinkler Study). Significant differences occurred among yearly means and sprinkler means (Table 5). Yearly means were 350, 358, 385, 371 and 409 mm for 1981, 1982, 1983, 1984 and 1985, respectively (Table 6). All yearly means were significantly different from each other except for the 1981 and 1982 values. Sprinkler means were 331, 378, 380 and 408 mm for I-344, I-172, S-103 and D-41 sprinklers, respectively.

Table 5. Statistical analysis summary of total water inputs for the sprinkler study.

Source	DF	Sum of Squares	F Value	PR > F	R Square	Coe. Var.
Model	7	46265.0	56.60	0.0001	0.9429	2.89
Error	24	2802.5				
Cor Tot	31	49067.5				
Y	4	9946.6	21.30	0.0001		
SP	3	18765.5	53.57	0.0001		

Table 6. Least-squares means of total water input variables for the sprinkler study.

Variable	Least-Squares Mean* (mm)
1981	350a
1982	358a
1983	385b
1984	371c
1985	409d
I-344	331a
I-172	378b
S-103	380b
D-41	408c

* Least-squares means with the same letter are not statistically different at the 5% level.

All sprinkler means were significantly different from each other except for the I-172 and S-103 values. A decrease in sprinkler pressure always resulted in an increase in total input. Sprinkler mean differences were unintentional. Pressure regulators on the I-172, S-103 and D-41 sprinklers were set at the beginning of the study to provide a uniform flow rate for all sprinklers. Laboratory measurements of sprinkler flow rates were taken at the conclusion of the study and averaged 0.685, 0.677, 0.712 and 0.704 L/s for the I-344, I-172, S-103 and D-41 sprinklers, respectively, for the specified operating pressure at the base of the sprinkler. The difference in the order of flow rates and total inputs among the sprinklers was probably caused by two main factors. Different spray losses among the sprinklers would affect total input values. Generally, spray losses increase as sprinkler pressures increase. Variations in irrigation system pressure or errors in pressure regulator settings would also affect sprinkler flowrates. Due to uncontrollable circumstances, irrigation system pressure was slightly less than 344 kPa on several occasions during the study, causing a reduction in I-344 flowrates. Also, field measurements of sprinkler pressures in 1985 revealed that the D-41 sprinklers were operating at an average pressure of 59 kPa, resulting in excessive flowrates. It is not known whether the pressure regulator were initially set incorrectly or if the settings changed during the course of the study.

Table 8. Statistical analysis summary of total runoff for the sprinkler study.

Source	DF	Sum of Squares	F Value	PR > F	R Square	Coe. Var.
Model	31	61977.2	27.78	0.0001	0.9179	33.58
Error	77	5540.8				
Cor Tot	108	67518.0				
Y	4	8648.5	30.05	0.0001		
ST	1	25211.7	350.37	0.0001		
SP	3	13020.4	60.31	0.0001		
Y *SP	8	1513.0	2.63	0.0134		
ST*SP	3	3617.5	16.76	0.0001		
Y *ST	4	3284.6	11.41	0.0001		
Y *ST*SP	8	1860.9	3.23	0.0032		

(Table 9). However, the 1983 mean (29 mm) was significantly different than the 1984 mean (20 mm).

For interaction I, a decrease in sprinkler pressure resulted in a significant increase in total runoff in all but three cases. Two of the exceptions occurred between the I-344 and I-172 sprinklers in 1983 and 1984, and the other was between the S-103 and D-41 sprinklers in 1983. The inverse relationship between sprinkler pressure and total runoff also existed for these three exceptions, but the means were not statistically different. An explanation for the inverse relationship between sprinkler pressure and total runoff is that application intensity increased as sprinkler pressure decreased (DeBoer and Beck, 1983). Assuming a constant soil

Table 9. Least-squares means of total runoff variables and interactions for the sprinkler study.

Variable or Interaction	Least-Squares Mean* (mm)
1981	INEST
1982	INEST
1983	29a
1984	20b
1985	INEST
IRT	INEST
Control	INEST
I-344	INEST
I-172	24
S-103	INEST
D-41	INEST
(I)	
1981 * I-344	31a
1981 * I-172	48b
1982 * I-344	21a
1982 * I-172	35b
1982 * S-103	51c
1983 * I-344	10a
1983 * I-172	15a
1983 * S-103	44b
1983 * D-41	46b
1984 * I-344	6a
1984 * I-172	12a
1984 * S-103	21b
1984 * D-41	40c
1985 * I-172	11a
1985 * S-103	22b
1985 * D-41	45c
(II)	
IRT * I-344	INEST
IRT * I-172	10
IRT * S-103	INEST
IRt * D-41	INEST
Control * I-344	INEST
Control * I-172	38
Control * S-103	INEST
Control * D-41	INEST

Table 9. Continued.

Variable or Interaction	Least-Squares Mean
(III)	
1981 * IRT	INEST
1981 * Control	INEST
1982 * IRT	INEST
1982 * Control	INEST
1983 * IRT	18a
1983 * Control	40b
1984 * IRT	3a
1984 * Control	36b
1985 * IRT	INEST
1985 * Control	INEST
(IV)	
1981 * IRT * I-344	16a
1981 * IRT * I-172	24a
1982 * IRT * I-344	2a
1982 * IRT * I-172	11a
1982 * IRT * S-103	15a
1983 * IRT * I-344	8a
1983 * IRT * I-172	13a
1983 * IRT * S-103	14a
1983 * IRT * D-41	36b
1984 * IRT * I-344	0a
1984 * IRT * I-172	0a
1984 * IRT * S-103	1a
1984 * IRT * D-41	12b
1985 * IRT * I-172	4a
1985 * IRT * S-103	10a
1985 * IRT * D-41	36b
1981 * Control * I-344	47a
1981 * Control * I-172	72b
1982 * Control * I-344	39a
1982 * Control * I-172	60b
1982 * Control * S-103	86c
1983 * Control * I-344	11a
1983 * Control * I-172	17a
1983 * Control * S-103	74b
1983 * Control * D-41	56c
1984 * Control * I-344	13a
1984 * Control * I-172	24a
1984 * Control * S-103	41b
1984 * Control * D-41	68c

Table 9. Continued.

Variable or Interaction	Least-Squares Mean
1985 * Control * I-172	19a
1985 * Control * S-103	35b
1985 * Control * D-41	55c

* Least-squares means with the same letter are not statistically different at the 5% level. Mean comparisons within interactions are only possible among common first variable(s).

infiltration rate and the same application depth for all sprinklers, a decrease in sprinkler pressure (i.e. an increase in application intensity) would produce an increase in runoff. The problems associated with this scenario were compounded in the field study in two ways. First, total input was not constant, but increased as sprinkler pressure decreased. Second, the soil at the research site has a crusting tendency. As application intensity increased, the rate at which a soil crust formed probably increased, thereby inhibiting infiltration. Both of these situations would cause a further increase in runoff.

Interactions II and III could not be analyzed in detail because many of the least-squares means were inestimable. For interaction III, however, IRT means were significantly less than Control means in 1983 and 1984.

For the year and IRT combinations in interaction IV, D-41 sprinklers always produced significantly more total runoff than I-344, I-172 and S-103 sprinklers. No significant differences occurred among other sprinkler means. For the year and Control combinations, a decrease in sprinkler pressure resulted in a significant increase in total runoff in all but three cases. The exceptions occurred between the I-344 and I-172 sprinklers in 1983 and 1984, and the S-103 and D-41 sprinklers in 1983. IRT means were always less than Control means. The IRT practice tended to reduce total runoff differences among sprinklers that existed for the Control treatment.

Total Runoff (Primary Tillage Study). Yearly means, primary tillage means, secondary tillage means and interaction means for year-by-sprinkler (I), year-by-secondary tillage (II) and secondary tillage-by-primary tillage (III) were significantly different (Table 10). Means were not significantly different for the year-by-primary tillage-by-secondary tillage interaction.

Yearly means were 38, 39, 22 and 18 mm for 1982, 1983, 1984 and 1985, respectively (Table 11). Mean values were not significantly different between years 1982 and 1983 or years 1984 and 1985, but 1982 and 1983 values were significantly different from 1984 and 1985 values. Primary tillage means were 34, 19 and 35 mm for Plowing,

Table 10. Statistical analysis summary of total runoff for the primary tillage study.

Source	DF	Sum of Squares	F Value	PR > F	R Square	Coe. Var.
Model	23	32488.3	13.94	0.0001	0.8745	34.86
Error	46	4662.8				
Cor Tot	69	37151.0				
Y	3	5865.5	19.29	0.0001		
PT	2	3518.2	17.35	0.0001		
ST	1	14312.0	141.19	0.0001		
Y *PT	6	3148.6	5.18	0.0004		
Y *ST	3	3558.9	11.70	0.0001		
ST*PT	2	1021.8	5.04	0.0105		
Y *PT*ST	6	858.1	1.41	0.2309		

Table 11. Least-squares means of total runoff variables and interactions for the primary tillage study.

Variable or Interaction	Least-Squares Mean* (mm)
1982	38a
1983	39a
1984	22b
1985	18b
Plow	34a
Disk	19b
Till-Plant	35a
IRT	15a
Control	44b
(I)	
1982 * Plow	41a
1982 * Disk	22b
1982 * Till-Plant	51a
1983 * Plow	53a
1983 * Disk	27b
1983 * Till-Plant	38b

significantly different in one-half of the cases, but no consistent relationships among primary tillage treatments were evident. For interaction II, IRT produced significantly less total runoff than the Control treatment in 1982, 1983 and 1984. IRT also produced less total runoff than Control in 1985, but the mean difference was not significant. IRT means in interaction III were 22, 8 and 15 mm for Plowing, Disking and Till-Planting, respectively. Plowing produced significantly more total runoff than Disking. Control means were 46, 31 and 55 mm for Plowing, Disking and Till-Planting, respectively. All means under the Control treatment were significantly different. IRT means were approximatly 1/4 of Control means for the Disking and Till-Planting practices, while the Plowing IRT mean was about 1/2 of the Control mean. The IRT practice tended to mask differences among primary tillage practices.

Ground Storage (Sprinkler Study). Differences occurred among yearly means, secondary tillage means, sprinkler means, and interaction means for year-by-secondary tillage (I) and secondary tillage-by-sprinkler (II) (Table 12). Yearly means were 31, -47, -24, -43 and 18 for 1981, 1982, 1983, 1984 and 1985, respectively (Table 13). Yearly means were not significantly different between years 1981 and 1985 and years 1982 and 1984. All

Table 12. Statistical analysis summary of ground storage for the sprinkler study.

Source	DF	Sum of Squares	F Value	PR > F	R Square	Coe. Var.
Model	15	96343.3	18.21	0.0001	0.7543	116.73
Error	89	31383.0				
Cor Tot	104	127726.3				
Y	4	74638.6	52.92	0.0001		
ST	1	16506.8	46.81	0.0001		
SP	3	3960.8	3.74	0.0139		
Y *ST	4	3894.1	2.76	0.0324		
ST*SP	3	3053.9	2.89	0.0400		

other yearly means showed significant differences. The IRT treatment (2 mm) produced significantly more storage than the Control treatment (-28 mm). Sprinkler means were -3, -13, -13 and -24 mm for I-344, I-172, S-103 and D-41 sprinklers, respectively. D-41 sprinklers produced significantly less storage than I-344 sprinklers. The other sprinkler means were not significantly different.

For interaction I, IRT produced significantly more storage than the Control treatment in 1981, 1982, 1983 and 1984. IRT also produced more storage than the Control treatment in 1985, but the means were not significantly different. IRT means for interaction II were 4, -1, 8 and -3 mm for I-344, I-172, S-103 and D-41 sprinklers, respectively. Means were not significantly different among sprinkler types. Control means were -9, -24, -34

Table 13. Least-squares means of ground storage variables and interactions for the sprinkler study.

Variable or Interaction	Least-Squares Mean* (mm)
1981	31a
1982	-47b
1983	-24c
1984	-43b
1985	18a
IRT	2a
Control	-28b
I-344	- 3a
I-172	-13ab
S-103	-13ab
D-41	-24 b
(I)	
1981 * IRT	56a
1981 * Control	10b
1982 * IRT	-36a
1982 * Control	-63b
1983 * IRT	-17a
1983 * Control	-33b
1984 * IRT	-23a
1984 * Control	-63b
1985 * IRT	24a
1985 * Control	13a
(II)	
IRT * I-344	4a
IRT * I-172	- 1a
IRT * S-103	8a
IRT * D-41	- 3a
Control * I-344	- 9a
Control * I-172	-24ab
Control * S-103	-34 bc
Control * D-41	-44 c

* Least-squares means with the same letter are not statistically different at the 5% level. Mean comparisons within interactions are only possible among a common first variable.

and -44 for I-344, I-172, S-103 and D-41 sprinklers, respectively. I-344 sprinklers produced significantly more storage than S-103 and D-41 sprinklers, and I-172 sprinklers produced significantly more storage than D-41 sprinklers. IRT means were greater than Control means for all sprinklers studied.

Ground Storage (Primary Tillage Study). Statistical differences occurred among yearly means, primary tillage means, secondary tillage means and year-by-secondary tillage interaction (I) means (Table 14). Interaction means were not significantly different for year-by-primary tillage, primary tillage-by-secondary tillage and year-by-primary tillage-by-secondary tillage.

Table 14. Statistical analysis summary of ground storage for the primary tillage study.

Source	DF	Sum of Squares	F Value	PR > F	R Square	Coe. Var.
Model	23	81011.2	10.35	0.0001	0.8410	53.07
Error	45	15318.9				
Cor Tot	68	96330.1				
Y	3	44159.3	43.24	0.0001		
PT	2	5504.4	8.08	0.0010		
ST	1	17679.1	51.93	0.0001		
Y *PT	6	2856.3	1.40	0.2362		
Y *ST	3	3260.9	3.19	0.0324		
PT*ST	2	1089.6	1.60	0.2131		
Y *PT*ST	6	1294.0	0.63	0.7027		

Yearly means were -45, -27, -69 and 2 mm for 1982, 1983, 1984 and 1985, respectively (Table 15). All means were significantly different from each other. Primary tillage means were -47, -28 and -29 mm for Plowing, Disking and Till-Planting, respectively. Plowing produced

Table 15. Least-squares means of ground storage variables and interactions for the primary tillage study.

Variable or Interaction	Least-Squares Mean* (mm)
1982	-45a
1983	-27b
1984	-69c
1985	2d
Plow	-47a
Disk	-28b
Till-Plant	-29b
IRT	-19a
Control	-51b
(I)	
1982 * IRT	-20a
1982 * Control	-70b
1983 * IRT	-12a
1983 * Control	-42b
1984 * IRT	-49a
1984 * Control	-88b
1985 * IRT	7a
1985 * Control	- 4a

* Least-squares means with the same letter are not statistically different at the 5% level. Mean comparisons within the interaction are only possible among a particular year.

significantly less storage than Disking and Till-Planting. Disking and Till-Planting means were not significantly different. IRT produced significantly more storage (-19 mm) than the Control treatment (-51 mm), which was consistent with the Sprinkler Study results.

For interaction I, IRT produced significantly more storage than Control in every year but 1985. IRT also produced more storage than Control in 1985, but the means were not significantly different. These interaction results are identical to those in the Sprinkler Study.

Total Evapotranspiration (Sprinkler Study). Yearly means, sprinkler means and year-by-sprinkler interaction (I) means were significantly different (Table 16). No significant differences occurred among secondary

Table 16. Statistical analysis summary of total evapotranspiration for the sprinkler study.

Source	DF	Sum of Squares	F Value	PR > F	R Square	Coe. Var.
Model	23	76160.9	55.21	0.0001	0.9937	2.13
Error	8	479.8				
Cor Tot	31	76640.7				
Y	4	42395.2	176.73	0.0001		
ST	1	165.3	2.76	0.1354		
SP	3	13874.0	77.11	0.0001		
Y *ST	4	638.2	2.66	0.1114		
Y *SP	8	2364.7	4.93	0.0184		
ST*SP	3	165.9	0.92	0.4728		

Table 17. Continued.

Variable or Interaction	Least-Squares Mean* (mm)
(I)	
1981 * I-344	246a
1981 * I-172	266b
1982 * I-344	334a
1982 * I-172	384b
1982 * S-103	351a
1983 * I-344	342a
1983 * I-172	398bc
1983 * S-103	381bc
1983 * D-41	401bd
1984 * I-344	341a
1984 * I-172	416b
1984 * S-103	396c
1984 * D-41	426d
1985 * I-172	380a
1985 * S-103	375a
1985 * D-41	390a

* Least-squares means with the same letter are not statistically different at the 5% level. Mean comparisons within the interaction are only possible among a particular year.

Total Evapotranspiration (Primary Tillage Study). Statistical differences occurred among yearly means, primary tillage means and secondary tillage-by-primary tillage interaction (I) means (Table 18). No significant differences occurred among secondary tillage means or year-by-primary tillage means.

Yearly means were 364, 357, 442 and 380 mm for years 1982, 1983, 1984 and 1985, respectively (Table 19).

Table 18. Statistical analysis summary of total evapotranspiration for the primary tillage study.

Source	DF	Sum of Squares	F Value	PR > F	R Square	Coe. Var.
Model	14	31321.6	28.61	0.0001	0.9780	2.29
Error	9	703.8				
Cor Tot	23	32025.3				
Y	3	27018.3	115.18	0.0001		
PT	2	1602.6	10.25	0.0048		
ST	1	60.2	0.77	0.4032		
Y *PT	6	1212.4	2.58	0.0970		
ST*PT	2	1428.1	9.13	0.0068		

Yearly means were significantly different from each other except for years 1982 and 1983. Primary tillage means were 394, 389 and 375 mm for Plowing, Disking and Till-Planting, respectively. Till-Planting produced significantly less total evapotranspiration than Plowing and Disking. Since the Till-Plant treatment produced considerably more residue cover than the Plow and Disk treatments, this decrease is probably due partly to reduced soil evaporation.

IRT means for interaction I were 390, 380 and 384 mm for Plowing, Disking and Till-Planting, respectively. No significant differences occurred among these IRT means. Control means were 398, 399 and 366 mm for Plowing, Disking and Till-Planting, respectively. Till-Planting produced significantly less total evapotranspiration than

Table 19. Least-squares means of total evapotranspiration variables and interactions for the primary tillage study.

Variable or Interaction	Least-Squares Mean* (mm)
1982	364a
1983	357a
1984	442b
1985	380c
Plow	394a
Disk	389a
Till-Plant	375b
(I)	
IRT * Plow	390a
IRT * Disk	380a
IRT * Till-Plant	384a
Control * Plow	398a
Control * Disk	399a
Control * Till-Plant	366b

* Least-squares means with the same letter are not statistically different at the 5% level. Mean comparisons within the interaction are only possible among a particular secondary tillage treatment.

Plowing and Disking. IRT means were less than Control means for Plowing and Disking but not for Till-Planting.

Average Daily Evapotranspiration (Sprinkler Study). Yearly and sprinkler mean differences occurred (Table 20). No significant differences occurred among secondary tillage means or interaction means for year-by-secondary tillage, year-by-sprinkler and secondary

Table 20. Statistical analysis summary of average daily evapotranspiration for the sprinkler study.

Source	DF	Sum of Squares	F Value	PR > F	R Square	Coe. Var.
Model	23	16.62	29.94	0.0001	0.9885	2.27
Error	8	0.19				
Cor Tot	31	16.81				
Y	4	5.48	56.73	0.0001		
ST	1	0.06	2.29	0.1684		
SP	3	4.72	65.13	0.0001		
Y *ST	4	0.23	2.42	0.1336		
Y *SP	8	0.63	3.26	0.0572		
ST*SP	3	0.08	1.07	0.4133		

tillage-by-sprinkler. A complete analysis of yearly and sprinkler means was impossible due to missing data (Table 21). However, yearly means were significantly different between years 1983 (6.7 mm) and 1984 (7.1 mm).

Average Daily Evapotranspiration (Primary Tillage Study). Significant differences occurred among yearly means, primary tillage means and secondary tillage-by-primary tillage interaction (I) means (Table 22). No significant differences occurred among secondary tillage means or interaction means for year-by-primary tillage and year-by-secondary tillage.

Yearly means were 6.5, 6.7, 7.9 and 8.1 mm for years 1982, 1983, 1984 and 1985, respectively (Table 23). The 1982 and 1983 means were significantly less than the

Table 21. Least-squares means of average daily evapotranspiration variables for the sprinkler study.

Variable or Interaction	Least-Squares Mean* (mm)
1981	INEST
1982	INEST
1983	6.7a
1984	7.1b
1985	INEST
I-344	INEST
I-172	7.0
S-103	INEST
D-41	INEST

* Least-squares means with the same letter are not statistically different at the 5% level.

Table 22. Statistical analysis summary of average daily evapotranspiration for the primary tillage study.

Source	DF	Sum of Squares	F Value	PR > F	R Square	Coe. Var.
Model	17	9.05	16.81	0.0011	0.9794	2.49
Error	6	0.19				
Cor Tot	23	9.24				
Y	3	7.45	78.40	0.0001		
PT	2	0.54	8.58	0.0174		
ST	1	0.01	0.33	0.5871		
Y *PT	6	0.42	2.23	0.1763		
Y *ST	3	0.04	0.43	0.7365		
ST*PT	2	0.58	9.21	0.0148		

1984 and 1985 means. Primary tillage means were 7.3, 7.2 and 6.9 mm for Plowing, Disking and Till-Planting, respectively. Till-Planting produced significantly less average daily evapotranspiration than Plowing and Disking.

IRT means in interaction I were 7.2, 7.0 and 7.1 mm for Plowing, Disking and Till-Planting, respectively. No significant differences occurred among IRT means.

Table 23. Least-squares means of average daily evapotranspiration variables and interactions for the primary tillage study.

Variable or Interaction	Least-Squares Mean* (mm)
1982	6.5a
1983	6.7a
1984	7.9b
1985	8.1b
Plow	7.3a
Disk	7.2a
Till-Plant	6.9b
(I)	
IRT * Plow	7.2a
IRT * Disk	7.0a
IRT * Till-Plant	7.1a
Control * Plow	7.4a
Control * Disk	7.4a
Control * Till-Plant	6.8b

* Least-squares means with the same letter are not statistically different at the 5% level. Mean comparisons within the interaction are only possible for a particular secondary tillage treatment.

Control means were 7.4, 7.4 and 6.8 mm for Plowing, Disking and Till-Planting, respectively. Till-Planting produced significantly less average daily evapotranspiration than either Plowing or Disking.

CONCLUSIONS

1. Calculated seasonal (52 days) deep percolation averaged four mm under a very wet soil and zero runoff conditions. Deep percolation should be negligible during the irrigation season.

2. Approximatly 80% of total water inputs was irrigation and the remainder was precipitation during a study period from late June to mid August. Surface runoff, soil water storage and evapotranspriation values were 8, -8 and 100% of total water input values during the study period.

3. Primary tillage practices produced variable responses on the water balance parameters. Disking produced the least surface runoff, Plowing the least soil water storage and Till-Planting the least evapotranspiration.

4. The inter-row (IRT) secondary tillage treatment, when compared to the Control treatment, reduced surface runoff and increased soil water storage but did not affect total evapotranspiration. The IRT practice moderated runoff differences among sprinklers and primary tillage treatments which were detected for the Control secondary treatment.

5. A decrease in sprinkler pressure produced an

increase in surface runoff and a decrease in soil water storage. Sprinklers with similar water inputs had no evapotranspiration differences.

6. Yearly evapotranspiration means ranged from 6.5 to 7.9 mm/day and averaged 7.1 mm/day.

ECONOMIC ANALYSIS

INTRODUCTION

The previous sections presented an analysis of the water cycle under the various tillage/sprinkler combinations. While these data are beneficial to the engineer, the economic feasibility of these various combinations is of ultimate importance to the producer. The development of an economic analysis methodology and the results of an economic analysis will be presented in this section of the thesis.

LITERATURE REVIEW

Irrigation Systems

The operating energy requirement of an irrigation system depends on a number of variables, many of which are site-specific (Thompson et al., 1983). Consequently, most literature compares different types of irrigation systems or determines relative energy differences for a particular system due to changes in one or more of the energy-equation variables. Only one empirical investigation was found in the literature. All other studies analyzed hypothetical cases using assumed variables common to a particular geographical area and/or irrigation system. Generally, the studies concluded that pressure reduction is an effective energy saving practice if irrigation efficiency is not significantly decreased. Percentage energy savings, due to a particular pressure reduction, decrease as static lift increases.

Potential irrigation energy savings due to a reduction in net depth of irrigation, a reduced total head (lower pressure requirement), improved pumping plant efficiency and increased irrigation efficiency were investigated by Gilley and Watts (1977). Graphs were developed to illustrate the potential percent energy savings in terms of final-to-initial value ratios of the above-mentioned variables. These graphs were used to calculate potential energy savings due to improvements in one or more of the variables for assumed conditions common to Nebraska. Potential savings ranged from 11 to 62%, depending on the type of energy source and the number of variable improvements.

Gilley and Mielke (1980) analyzed the problems of reduced-pressure center-pivot systems, presented possible solutions to these problems and showed the potential energy savings of reduced pressure. The only variables considered in the energy saving analysis were total dynamic head (a function of static lift, sprinkler pressure and friction loss) and irrigation efficiency. Various graphs were presented relating pressure ratio, lift-to-pressure ratio and percent energy savings. It was shown that for a low lift-to-pressure ratio (e.g. 0.2) a 50% reduction in pivot pressure produced a 42% energy savings. This same pressure reduction for a larger lift-to-pressure ratio (1.5) only resulted in a 20% energy savings. A graph illustrating the break-even analysis for reduced-pressure center-pivot systems was also included. For a given lift-to-pressure ratio and a given pivot pressure ratio, the graph could be used to find the maximum allowable change in irrigation efficiency to maintain a positive energy savings.

White and Stutler (1980) presented a procedure to analyze the economic feasibility of irrigation pumping plant improvements. Economic considerations included the time value of money (term and interest rate), energy cost escalation, income tax increases, depreciation and investment credit. The useful life of repair investments was the dominant variable of the assumed economic conditions (interest rate, price escalation and useful life), while the internal rate of return was the principal factor affecting the final investment decision. Internal rate of return is the interest rate received on the repair investment if the efficiency of the pumping plant is increased to an anticipated efficiency. The authors concluded that commonly used estimates to analyze economic feasibility of pumping plant repair are conservatively inadequate when escalation of energy costs and income tax implications are considered.

Trade-offs between pumping energy requirements, embodied energy requirements, water requirements and costs for a wide range of irrigation system designs under assumed crop and site conditions (cotton grown in the San Joaquin Valley of California) were analyzed by Hagan and Roberts (1981). An inexpensive, low-energy surface water supply was assumed. Total pumping energy for a center pivot system equipped with low-pressure (276 kPa) impact heads was 21% greater than a system with low-pressure (138 kPa) spray nozzles, even though the impact sprinklers used six percent less irrigation water than the spray nozzles. The difference in water use occurred because the system with spray nozzles irrigated more times with a slightly lower application depth in order to alleviate runoff problems caused by the high application intensity of the spray nozzles.

Bosch et al. (1982) described a methodology to determine the energy savings associated with a center pivot system pressure reduction. Worksheets were presented using White and Stutler's procedure to determine the economic feasibility of converting a center pivot irrigation system from high to low pressure.

Economic benefits of gated-pipe surface and center pivot sprinkler irrigation systems for several initial operating conditions were analyzed by Gilley and Supalla (1983). Pressure reduction was the most beneficial energy saving practice for a center pivot system, followed by pumping plant adjustment, irrigation water management and irrigation application efficiency.

Von Bernuth and Gilley (1985) described a process to economically compare application packages. Pumping power requirements were divided by a runoff factor to obtain relative pumping power (RPP). RPP was compared with actual pumping costs to determine the best application option. Values of RPP were listed for varying flow rates, pumping lifts, soil types, application packages and surface storage depths.

Taylor (1986) presented results from an empirical study of reduced pressure irrigation systems in Brookings County, SD. A field survey of 37 irrigators operating 57 electrically powered center pivot systems for corn production was performed in 1982. Pivot pressures ranged from 150 to 595 kPa and averaged 365 kPa. The impact of reduced pressure on yield and energy cost was identified. Results were used to analyze the economics of investment decisions for initial system purchase and conversion from high to low pressure. No yield changes were found with reduced pressure irrigation. It was shown, however, that a relatively small decrease in yields (less than five percent) could outweigh any benefits of reduced pressure energy savings. Energy costs for the high pressure (515 kPa) pivots was $6.15/ha higher than that for the low pressure (205 kPa) center pivots, but this difference was not statistically significant. However, above-normal precipitation in 1982 reduced the irrigation demand by approximately 60%. When the normal irrigation demand was used in the analysis, annual energy cost savings with low rather than high pressures were found to be between $25 and $30/ha, or between #1335 and $1600 per center pivot per year.

Tillage Practices

Total tillage energy requirement is simply the sum of individual tillage energy requirements. Energy requirements vary widely among tillage operations and soil types. Much research has been conducted in the last 10 to 15 years concerning energy requirements for tillage operations. Most of this research involved direct measurement of draft and/or fuel consumption for a variety of tillage operations and a particular soil type. There is wide variability, however, in experimental techniques and reporting procedures. Bowers (1985) addressed this problem and recommended standard reporting procedures for U.S. tillage energy studies based on 1984 ASAE Standards. Since soil type is an important factor in tillage energy usage, the following literature review will only reference experiments conducted on silt loam soils.

Frisby and Summers (1979) measured draft and fuel consumption for six tillage and two planting implements on Missouri soils. Draft was measured with an extended-ring, strain gauge load-cell, drawbar dynamometer. Fuel consumption was measured using a vortex flowmeter. Results were given in terms of mean values and standard deviation.

Results from an on-farm survey of Nebraska farmers were presented by Shelton et al. (1980). Fuel consumption for tillage, planting, harvesting and miscellaneous operations was measured using supply tank meters. Weighted average, mean and standard deviation values were listed.

Griffith and Parsons (1981) compiled fuel consumption values for most field operations used in corn production. The data are averages of those reported in extension publications from several Corn Belt states for moderate draft soils (loams and silt loams). Fuel consumption for conventional, chisel and no-till systems were compared using these values.

Draft and fuel consumption for a number of residue preparation, tillage, planting and weed control processes were measured by Stephens et al. (1981). Tests were conducted in Iowa and Illinois.

Self et al. (1983) measured draft and power requirements for various combinations of seven implement types. Projections of total power and fuel requirements for primary and secondary tillage implements were made.

A literature review of tillage energy data for Southeastern U.S. soils was compiled by Bowers (1985). Values from work done on silt loam soils by Trouse and Reaves (1980) and Dumas and Renoll (1982) are listed.

PROCEDURE

Computer Model

A computer model was written which analyzes pumping requirement, tillage sequence and crop yield for an irrigated crop. Yearly costs of the above-mentioned variables can be calculated for a given production system. The model also calculates the economic feasibility of potential modifications to irrigation and/or tillage systems. Modifications are economically analyzed by comparing before and after production costs, with the difference converted to a present worth value for an assumed interest rate and time period. Present worth represents the maximum amount that can be profitably invested in the modifications. The methodology used by the computer model is outlined in the following steps. Before and after values are subscripted with a one and two, respectively.

Step 1. Calculate pumping cost difference.

$$PCD = (PE_1 - PE_2) * PEC \quad (7)$$

$$PE = \frac{0.0271 * AR * D * H}{Ei * Ep} \quad (8)$$

$$H = L + (0.102 * PR) + F \quad (9)$$

$$Ei = 1 - S - RU - DEP \quad (10)$$

where

PCD = pumping cost difference; $

PE = pumping energy; kWh

PEC = pumping energy cost; \$/kWh

AR = irrigated area; ha

D = yearly irrigation requirement; mm

H = total dynamic head; m

Ei = irrigation efficiency; decimal

Ep = pumping efficiency; decimal

L = static lift; m

PR = system pressure; kPa

F = friction and minor loss; m

S = spray loss (percent of water leaving the irrigation system that fails to reach the crop canopy); decimal

RU = runoff (percent of water reaching the crop canopy that fails to infiltrate); decimal

DEP = deep percolation (percent of water infiltrating that leaches through the root zone); decimal

<u>Step 2. Calcuate tillage cost difference.</u>

$$TCD = (TE_1 - TE_2) * TEC \quad (11)$$

$$TE = FC * AR \quad (12)$$

where

TCD = tillage cost difference; \$

TE = tillage energy; L of fuel

TEC = tillage energy cost; \$/L

FC = fuel consumption; L/ha

AR = field size; ha

<u>Step 3. Calculate yield income difference.</u>

$$YID = (GY_2 - GY_1) * AR * GC \quad (13)$$

where

YID = yield income difference; $

GY = grain yield; kg/ha

AR = field size; ha

GC = grain cost; $/kg

Step 4. Calculate yearly cost difference.

$$CD = PCD + TCD + YID \quad (14)$$

where

CD = yearly cost difference; $

PCD = pumping cost difference; $

TCD = tillage cost difference; $

YID = yield income difference; $

Step 5. Calculate present worth of yearly cost difference.

$$PW = CD * AF \quad (15)$$

$$AF = \frac{1 - (1 + i)^{-n}}{i} \quad (16)$$

where

PW = present worth of yearly cost difference; $

CD = yearly cost difference; $

AF = amortization factor; unitless

i = interest rate; decimal

n = period of analysis; years

Taylor (1986) used this same uniform-series amortization factor to evaluate the feasibility of irrigation system conversion in a study where only system pressure was a pertinent paramater.

Step 6. Calculate present worth of yearly cost difference assuming price variations (Optional). The preceding analysis is based upon current prices. If price variations are expected in any of the cost variables, Equations 7, 11 and/or 13 must be multiplied by a factor accounting for changes in energy costs, fuel costs and/or grain prices, respectively. This factor is determined using (Pearson, 1974 as cited by Thompson et al., 1980):

$$PVF = \frac{(1 + r)^n - (1 + i)^n}{(1 + r) - (1 + i)} * \frac{i}{(1 + i)^n - 1} \qquad (17)$$

where

PVF = price variation factor; unitless

r = expected price variation rate during analysis period; decimal

i = interest rate; decimal

n = analysis period; years

Equation 17 can not be used if the values for interest rate and escalation rate are equal.

Economic Analysis

The computer model was used to determine the economic feasibility of converting an assumed production system to one of the experimental tillage/sprinkler combinations studied. The Disk/I-344 combination was chosen as the assumed initial condition since it is representative of regional production systems and because values for pumping cost variables were available from the field research. Pumping and tillage were the only cost variables analyzed. Yields (Appendix F) were not significantly different at the five percent level (DeBoer, 1986) and were consequently not analyzed. A seven year analysis period, 10% interest and zero price variation for all cost variables were the assumed economic variables.

Irrigated area (AR) was assumed to be 53 ha, the area typically irrigated by a center pivot irrigation machine. Yearly irrigation requirement (D) is the amount of water required by the crop to obtain optimum yields. Field research values that most closely approximate yearly irrigation requirements are the calculated evapotranspiration depths. These evapotranspiration values, however, may not accurately represent crop water needs. It is the author's opinion that crop transpiration occurred partly because adequate water was available, regardless of whether the transpiration was needed for maximum crop yields. This theory is supported by the fact that no significant yield differences occurred for the varying evapotranspiration amounts. The fact that the evapotranspiration data are based on only part of the irrigation season poses another problem. Calculated yearly pumping costs, using the evapotranspiration values, could be too low since irrigations prior to cultivation were not included. For these reasons, three values of yearly irrigation requirement (300, 400 and 500 mm) were analyzed. These values represent a range typical for the Midwest. Irrigation efficiency (Ei) was calculated using measured runoff values and assumed spray loss (S) values of 20% for the I-344 sprinklers, 10% for the I-172 and S-103 sprinklers and 5% for the D-41 and S-41 sprinklers (DeBoer, 1986) (Appendix F). Deep percolation was assumed to be zero. Data from 1982-1985 were averaged for a particular tillage/sprinkler combination to obtain a single irrigation efficiency value for each tillage/-sprinkler combination. Data from 1981 was eliminated since only two sprinkler types were used in the sprinkler study and because S-41 sprinklers were used in the primary tillage study. In order to have all averages based on four years of data, subjective estimates were made for D-41 data in 1982 and I-344 data in 1985. Static lift (L) at the site was 75 m. System pressure (PR) equaled the sprinkler operating pressure plus pressure loss in the mainline (loss was assumed to be 90 kPa for a center-pivot). Friction and minor loss (F) in the delivery system was assumed to be 18.3 m based upon a system length of 1830 m and a friction gradient of 0.01.

Pumping plant efficiency (Ep) was assumed to be 65% (DeBoer et al., 1983), and energy cost (EC) was assumed to be 0.07 $/kWh.

Fuel consumption (FC) for all field operations except IRT were determined using data from Griffith and Parsons (1981). Draft and velocity measurements were made for IRT by DeBoer and Beck (1982). Fuel requirements of 8.3 L/ha were determined for IRT using the draft and velocity measurements, a field capacity of 2.6 ha/h and an assumed tractive efficiency of 90% (Bowers, 1985). Griffith and Parson's data and a table summarizing estimated tillage fuel requirements are shown in Appendix F. Energy cost (EC) was assumed to be 0.18 $/L.

RESULTS AND DISCUSSION

Computer Model

A lising of the economic analysis computer program is given in Appendix G.

Economic Analysis

It must be remembered that calculated dollar values in the following tables are site specific and based on several assumptions. These values, however, do provide approximations for central South Dakota and allow relative comparisons among the various tillage/sprinkler combinations.

Positive values for pumping, tillage and total cost differences indicate yearly savings as compared to the Disk/Control/I-344 combination. These values were multiplied by an amortization factor to obtain present worth values. Consequently, present worth values have the same relationship among each other as cost difference values. Modifications requiring an initial investment greater than the present worth value are not economically feasible. The amortization factor for the assumed economic conditions (10% interest and a seven year analysis period) equaled 4.87.

Yearly Pumping Cost Differences. Every tillage/sprinkler combination produced a yearly savings in pumping costs when compared to the Standard (Table 24). Pumping cost savings were caused by a larger irrigation efficiency and/or a lower sprinkler pressure than the Standard (Equations 7 and 8) and ranged from $649 for the Disk/IRT/I-344/300 mm combinations to $4803 for the Disk/IRT/D-41/500 mm combination. Larger savings are produced with increased field size, irrigation requirement, static lift or friction loss and/or decreased pumping or irrigation efficiency (Equation 8). Conse-

Table 24. Yearly pumping cost differences for a 53 ha field.

Primary Tillage	Secondary Tillage	Sprinkler Type	Irr. Requirement (mm) 300	400	500
SPRINKLER STUDY			puming cost diff. ($)		
Disk	IRT	I-344	649	866	1082
		I-172	2306	3075	3843
		S-103	2610	3480	4350
		D-41	2882	3843	4803
Disk	Control	I-344	STANDARD OF COMPARISON		
		I-172	1757	2343	2928
		S-103	1247	1662	2078
		D-41	2122	2829	3536
PRIMARY TILLAGE STUDY					
Plow	IRT	I-172	1923	2564	3206
	Control	I-172	1205	1607	2008
Disk	IRT	I-172	2306	3075	3843
	Control	I-172	1671	2228	2784
Till	IRT	I-172	2158	2878	3597
Plant	Control	I-172	894	1192	1491

quently, pumping cost savings always increased as irrigation requirement varied from 300 to 500 mm. Tillage/sprinkler combinations can be compared using the values in Table 24. For instance, a $718 savings would occur for the Plow/I-172/300 mm combination if IRT rather than Control was used as the secondary tillage treatment ($1923-$1205).

For a particular irrigation depth, an inverse relationship between sprinkler pressure and cost difference existed among all sprinklers except I-172 and S-103 for the Control secondary tillage treatment. The benefits of this pressure drop were overcome by a decrease in irrigation efficiency (Table F-6). Since the same spray loss was assumed for these two sprinklers, the decrease in irrigation efficiency was due entirely to runoff differences (Equation 10).

The Disking primary tillage treatment produced the largest cost savings for both the IRT and Control practices. Plowing produced the least savings for the IRT treatment and Till-Planting produced the least savings for the Control treatment. Cost savings in the primary tillage study were due entirely to runoff differences.

IRT always produced a larger savings than the Control treatment for a particular sprinkler or primary tillage operation. IRT values were at least twice as large as Control values for the I-172 sprinkler and the Till-Plant primary tillage treatment. IRT values were approximatly 50% larger than Control values for the remaing sprinklers and primary tillage treatments.

The Disk/Control/I-172 combination occurred in both the Sprinkler and Primary Tillage Study but produced different pumping cost savings. Runoff was greater in the Primary Tillage Study, resulting in a lower cost savings. Pumping cost savings were identical for the Disk/IRT/I-172 since the same irrigation efficiency occurred in both studies.

Present Worth Values of Pumping Cost Differences. Present worth values ranged from $3161 to $23,384 for the assumed economic conditions (Table 25). A lower interest rate and/or a longer analysis period would increase these present worth values.

Yearly Tillage Cost Differences and Associated Present Worth Values. All tillage sequences but one (Till-Plant, Cultivate) produced a larger yearly cost than the Standard (Table 26). Yearly cost differences ranged from $-253 for the Plow/IRT sequence to $40 for the Till-Plant/Control sequence, producing present worth values of $-1231 and $195, respectively. These cost difference and present worth values are small compared to their pumping counterparts. The potential pumping cost

Table 25. Present worth values of yearly pumping cost differences for a seven year period of analysis and 10% interest.

Primary Tillage	Secondary Tillage	Sprinkler Type	Irr. Requirement (mm) 300	400	500
SPRINKLER STUDY			present worth ($)		
Disk	IRT	I-344	3161	4215	5269
		I-172	11227	14969	18711
		S-103	12705	16941	21176
		D-41	14030	18707	23384
Disk	Control	I-344	STANDARD OF COMPARISON		
		I-172	8554	11405	14257
		S-103	6069	8093	10116
		D-41	10330	13773	17217
PRIMARY TILLAGE STUDY					
Plow	IRT	I-172	9364	12485	15606
	Control	I-172	5866	7821	9777
Disk	IRT	I-172	11227	14969	18711
	Control	I-172	8134	10845	13557
Till	IRT	I-172	10507	14010	17512
Plant	Control	I-172	4354	5806	7257

Table 26. Yearly tillage cost differences for a 53 ha field and associated present worth values for a seven year period of analysis and 10% interest.

Tillage Sequence	Cost Diff. ($)	Present Worth ($)
Disk, Plant, Cultivate, IRT	- 79	- 385
Disk, Plant, Cultivate	STAN. OF	COMP.
Plow, Disk, Plant, Cultivate, IRT	-253	-1231
Plow, Disk, Plant, Cultivate	-174	- 845
Till-Plant, Cultivate, IRT	- 39	- 190
Till-Plant, Cultivate	40	195

savings produced by the IRT treatment are larger than the associated increase in tillage costs.

Total Yearly Cost Differences. Since the negative tillage cost differences were small compared to the positive pumping cost differences, all tillage/sprinkler combinations had positive total cost differences, most of which were slightly less than pumping cost differences (Table 27). Total cost difference values ranged from $570 to $4724. Sprinkler relationships were identical to those

Table 27. Total yearly cost differences for a 53 ha field.

Primary Tillage	Secondary Tillage	Sprinkler Type	Irr. Requirement (mm) 300	400	500
SPRINKLER STUDY			total cost diff. ($)		
Disk	IRT	I-344	570	787	1003
		I-172	2227	2996	3764
		S-103	2531	3401	4271
		D-41	2803	3764	4724
Disk	Control	I-344	STANDARD OF COMPARISON		
		I-172	1757	2343	2928
		S-103	1247	1662	2078
		D-41	2122	2829	3536
PRIMARY TILLAGE STUDY					
Plow	IRT	I-172	1670	2311	2953
	Control	I-172	1031	1433	1834
Disk	IRT	I-172	2227	2996	3764
	Control	I-172	1671	2228	2784
Till	IRT	I-172	2119	2839	3558
Plant	Control	I-172	934	1232	1531

for pumping cost differences. IRT values were still always greater than Control values, but total differences were slightly less than pumping cost differences. Primary tillage relationships were also the same as those for pumping cost differences.

Present Worth Values of Total Cost Differences. Present worth values associated with total yearly cost differences ranged from $2776 to $22,999 (Table 28).

Table 28. Present worth values of total yearly cost differences for a seven year period of analysis and 10% interest.

Primary Tillage	Secondary Tillage	Sprinkler Type	Irr. Requirement (mm) 300	400	500
SPRINKLER STUDY			total present worth ($)		
Disk	IRT	I-344	2776	3830	4884
		I-172	10842	14584	18326
		S-103	12320	16556	20791
		D-41	13645	18322	22999
Disk	Control	I-344	STANDARD OF COMPARISON		
		I-172	8554	11405	14257
		S-103	6069	8093	10116
		D-41	10330	13773	17217
PRIMARY TILLAGE STUDY					
Plow	IRT	I-172	8133	11254	14375
	Control	I-172	5021	6976	8932
Disk	IRT	I-172	10842	14584	18326
	Control	I-172	8134	10845	13557
Till	IRT	I-172	10317	13820	17322
Plant	Control	I-172	4549	6001	7452

CONCLUSIONS

1. A computer model was sucessfully written which determined the relative savings of irrigation system and/-or tillage practice modifications.

2. Pumping cost savings dominated tillage cost savings in the economic analysis.

3. The Disking primary tillage treatment was economically superior to the Plowing and Till-Planting treatments for both IRT and Control secondary tillage practices.

4. Sprinkler pressure reduction was cost effective for all pressures (344 kPa, 172 kPa, 103 kPa and 41 kPa) even though surface runoff increased with a decrease in pressure.

5. The inter-row tillage (IRT) treatment produced larger cost savings than the Control treatment for all sprinklers and primary tillage treatments used in this study.

REFERENCES

Baker, J.L., J.M. Laflen and H.P. Johnson. 1978. Effect of tillage systems on runoff losses of pesticides. A rainfall simulation study. Transactions of the ASAE 21(5):886-892.

Baker, J.L., J.M. Laflen and R.O. Hartwig. 1982. Effects of corn residue and herbicide placement on herbicide runoff losses. Transactions of the ASAE 25(2):340-343.

Bosch, D., V. Eidman and J. Wright. 1982. Determining the economic feasibility of converting center pivot irrigation systems from high pressure to low pressure. Unpublished report, Department of Agricultural and Applied Economics, University of Minnesota, St. Paul, MN. 10p.

Bowers, C.G. Jr. 1985. Southeastern tillage energy data and recommended reporting. Transactions of the ASAE 28(3):731-737.

Brooks, R.H. and A.T. Corey. 1964. Hydraulic properties of porous media. Hydrol. Paper No. 3, Colorado State University, Fort Collins, 27 p.

DeBoer, D.W., D.D. Brosz and J.L. Wiersma. 1977. Irrigation application depths for optimum crop production. Transactions of the ASAE 20(6):1067-1069, 1078.

DeBoer, D.W. and D.L. Beck. 1982. Tillage practice to enhance infiltration under sprinkler irrigation. ASAE Paper No. 82-2002, ASAE, St. Joseph, MI. 49085.

DeBoer, D.W. and D.L. Beck. 1983. Field evaluation of reduced pressure sprinklers. ASAE Paper No. 83-2024, ASAE, St. Joseph, MI. 49085.

DeBoer, D.W., D.R. Lundstrom and J.A. Wright. 1983. Efficiency analysis of electric irrigation pumping plants in the upper Midwest, U.S.A. Elsevier, Energy in Agriculture 2(1):51-59.

DeBoer, D.W. 1986. Personal correspondence with D.W. DeBoer, Professor. Agricultural Engineering Department, South Dakota State University, Brookings, SD. 57007.

Dumas, W.T. and E. Renoll. 1982. Energy and machinery management for cotton production systems. ASAE Paper No. 82-1027, ASAE, St. Joseph, MI. 49085.

Fischbach, P.E. and B.R. Somerhalder. 1974. Irrigation design requirements for corn. Transactions of the ASAE 17(1):162-165, 167.

Frisby, J.C. and J.D. Summers. 1979. Energy-related data for selected implements. Transactions of the ASAE 22(5):1010-1011.

Gilley, J.R. and D.G. Watts. 1977. Possible energy savings in irrigation. Journal of the Irrigation and Drainage Division 103(IR4):445-457.

Gilley, J.R. and L.N. Mielke. 1980. Conserving energy with low-pressure center pivots. Journal of the Irrigation and Drainage Division 106(IR1):49-59.

Gilley, J.R. and R.J. Supalla. 1983. Economic analysis of energy saving practices in irrigation. Transactions of the ASAE 26(6):1784-1792.

Gilley, J.R., L.N. Mielke and W.W. Wilhelm. 1983. An experimental center-pivot irrigation system for reduced energy crop production studies. Transactions of the ASAE 26(5):1375-1379, 1385.

Gilley, J.R., D.R. Hay and J.L. LaRue. 1986. Low pressure sprinkler packages for moving irrigation systems. ASAE Paper No. 86-2088, ASAE, St. Joseph, MI. 49085

Griffith, D.R. and S.D. Parsons. 1981. Energy requirements for tillage planting systems. Proceedings, ASAE Conference on Crop Production with Conservation in the 80's, Palmer House, Chicago, IL.

Hagan, R.M. and E.B. Roberts. 1981. Energy, water and cost trade-offs in irrigation system selection and management. Transactions of the ASAE 24(6):1539-1545.

Hanna, A.Y., P.W. Harlan and D.T. Lewis. 1983. Effect of slope on water balance under center pivot irrigation. Soil Science Society of America Proceedings 47:760-763.

Kincaid, D.C., E.G. Kruse, H.R. Duke and D.F. Champion. 1979. Evapotranspiration computed to estimate leaching fractions. Transactions of the ASAE 22(2):310-314, 319.

Kohl, K. 1985. Physical properties of Lowry silt loam. Unpublished report, Agricultural Engineering Department, South Dakota State University, Brookings, SD. 57007.

McGregor, J.D. and J.D. Greer. 1982. Erosion control with no-till and reduced till corn for silage and grain. Transactions of the ASAE 25(1):154-159.

Mannering, J.V., L.D. Meyer and C.B. Johnson. 1966. Infiltration and erosion as affected by minimum tillage for corn. Soil Science Society of America Proceedings 30:101-105.

Moshref-Javadi, A. 1986. Effect of sprinkler type and tillage practice on a soil infiltration parameter under a moving sprinkler irrigation system. Unpublished M.S. thesis, South Dakota State University Library, Brookings, SD. 57007.

Onstad, C.A. 1972. Soil and water losses as affected by tillage practices. Transactions of the ASAE 15(2):-287-289.

Pearson, G.F. 1974. Life-cycle costing in an energy crisis era. Professional Engineer 44(7):22-29, Washington, DC.

Phillips, R.E., R.L. Blevins, G.W. Thomas, W.W. Frye and S.H. Phillips. 1980. No-tillage agriculture. Science 208:1108-1113.

Rosenthal, W.D., E.T. Kanemasu, R.J. Raney and L.R. Stone. 1977. Evaluation of an evapotranspiration model for corn. Agronomy Journal 69:461-464.

Self, K.P., A. Khalilian, D.G. Batchelder, P.D. Bloome and G. Piethmuller. 1983. Draft and power requirements of tillage implements in Oklahoma soils. ASAE Paper No. 83-1038, ASAE, St. Joseph, MI. 49085.

Shelton, D.P., K. Van Bargen and A.S. Al-Jiburi. 1980. Nebraska on-farm fuel use survey. Transactions of the ASAE 23(5):1089-1092.

Skaggs, R.W., D.E. Miller and R.H. Brooks. 1983. Soil Water. In: Design and Operation of Farm Irrigation Systems (Editor M.E. Jensen) ASAE Monograph #3, ASAE, St. Joseph, MI. 49085.

Steel, R.G.D. and J.H. Torrie. 1980. PRINCIPLES AND PROCEDURES OF STATISTICS, 2nd ed., McGraw Hill Book Company, New York. pp. 443-449.

Stephens, L.E., A.D. Spencer, V.G. Floyd and W.W. Brixius. 1981. Energy requirements for tillage and planting. ASAE Paper No. 81-1512, ASAE, St. Joseph, MI. 49085.

Sternitzke, D.A. and R.L. Elliott. 1986. Estimates of evapotranspiration in the Oklahoma Panhandle Region. ASAE Paper No. 86-2003, ASAE, St. Joseph, MI. 49085.

Stewart, J.I., R.D. Misra, W.O. Pruitt and R.M. Hagan. 1975. Irrigating corn and grain sorghum with a deficient water supply. Transactions of the ASAE 18(2):-270-280.

Taylor, D.C. 1986. Reduced pressure irrigation investment economics. Water Resources Research 22(2):121-128.

Thompson, G.T., L.B. Spiess and J.N. Krider. 1983. Farm resources and system selection. In: Design and Operation of Farm Irrigation Systems (Editor M.E. Jensen) ASAE Monograph #3, ASAE, St. Joseph, MI. 49085.

Trouse, A.C. Jr. and C.A. Reaves. 1980. Reducing energy inputs into no-tillage systems. 3rd Annual Southeastern No-Tillage Conference, June 1980, Williston, FL. pp 188-195.

von Bernuth, R.D. and J.R. Gilley. 1985. Evaluation of center pivot application packages considering droplet induced infiltration reduction. Transactions of the ASAE 28(6):1940-1946.

White, J.C. and R.K. Stutler. Economic analysis for improving irrigation pumping plant efficiencies. ASAE Paper No. 80-3039, ASAE, St. Joseph, MI. 49085.

APPENDICES

APPENDIX A

List of symbols

Table A-1. List of symbols, definitions and units.

Symbol	Definition	Units
A	regression constant	unitless
AF	amortization factor	unitless
AR	area irrigated or tilled	ha
B	regression constant	unitless
C	regression constant	unitless
CD	yearly cost difference	$
D	yearly irrigation requirement	mm
DEP	deep percolation (percent of water infiltrating that leaches through the root zone)	decimal
DP	deep percolation	mm
Ei	irrigation efficiency	decimal
Ep	pumping efficiency	decimal
ET	evapotranspiration	mm
F	friction and minor losses	m
FC	fuel consumption	L/ha
h	matric potential	mm
dh/dz	matric potential gradient	mm/mm
GC	grain cost	$/kg
GS	ground storage (positive for increases, negative for decreases)	mm
GY	grain yield	kg/ha
H	total dynamic head	m
i	interest rate	decimal

Table A-1. Continued.

Symbol	Definition	Units
I	irrigation water reaching the crop canopy	mm
Ks	saturated hydraulic conductivity	mm/h
Ku	unsaturated hydraulic conductivity	mm/h
L	static lift	m
M	moisture content	mm^3/mm^3
Mr	residual moisture content	mm^3/mm^3
Ms	saturation moisture content	mm^3/mm^3
n	analysis period	years
P	precipitation	mm
PCD	pumping cost difference	$
PE	pumping energy	kWh
PEC	pumping energy cost	$/kWh
PR	system pressure	kPa
PT	primary tillage	unitless
PVF	price variation factor	unitless
PW	present worth value	$
r	expected price variation rate during analysis period	decimal
R	runoff	mm
RU	runoff (percent of water reaching the crop canopy that fails to infiltrate)	decimal
S	spray loss (percent of water leaving the irrigation system that fails to reach the crop canopy)	decimal

Table A-1. Continued.

Symbol	Definition	Units
SP	sprinkler type	unitless
ST	secondary tillage	unitless
TCD	tillage cost difference	$
TE	tillage energy	L
TEC	tillage energy cost	$/L
V	Darcian velocity	mm/h
Y	year	unitless
YID	yield income difference	$

APPENDIX B

Precipitation events and associated estimated runoff

Table B-1. Precipitation events and associated estimated runoff.

Date	Rainfall (mm)	Secondary Tillage IRT	Control
		est. runoff (mm)	
7/08/81	11	0	0
7/11/81	2	0	0
7/15/81	6	0	0
7/17/81	7	0	0
7/21/81	1	0	0
7/22/81	3	0	0
7/23/81	1	0	0
7/24/81	3	0	0
7/25/81	3	0	0
7/29/81	11	0	0
7/30/81	1	0	0
7/31/81	9	0	0
8/01/81	45	15	20
8/05/81	2	0	0
8/07/81	3	0	0
8/09/81	1	0	0
8/13/81	2	0	0
8/16/81	19	0	0
7/06/82	3	0	0
7/12/82	7	0	0
7/16/82	1	0	0
7/20/82	5	0	0
7/22/82	8	0	0
7/25/82	15	0	0
7/26/82	10	0	0
6/28/83	14	0	0
7/01/83	20	0	0
7/03/83	22	0	0
7/18/83	23	0	1
7/27/83	33	6	7
7/28/83	13	0	0
7/29/83	8	0	0
6/30/84	12	0	0
7/03/84	2	0	0
7/26/84	8	0	0
8/03/84	2	0	0
8/14/84	10	0	0

Table B-1. (continued).

Date	Rainfall (mm)	Secondary Tillage IRT	Control
		est. runoff (mm)	
8/16/84	21	0	0
6/27/85	4	0	0
7/17/85	2	0	0
7/24/85	4	0	0
7/30/85	14	0	0
8/06/85	2	0	0
8/12/85	3	0	0

APPENDIX C

Specific research results of deep percolation measurements

In the following tables, test locations within plots are referred to as "top" and "bottom". The irrigation machine traveled from the top to the bottom of the plots. Runoff ran towards the bottom of the plots.

Table C-1. Moisture release curve at research site for 1.30-1.40 m soil profile.[a]

Matric (mm)	Potential (bars)	Volumetric Water Content
1.02	0.1	0.322
2.04	0.2	0.299
3.06	0.3	0.250
6.12	0.6	0.189
10.20	1.0	0.186
30.59	3.0	0.146
61.19	6.0	0.117
101.98	10.0	0.111
152.97	15.0	0.110

[a] Reference: Kohl, 1985.

Table C-2. Variable values for Brooks-Corey equations.

Variable	Value	Units
Ms	0.506	mm^3/mm^3
Mr	0.065	mm^3/mm^3
A	3.571	unitless
B	0.379	unitless
C	8.277	unitless
Ks	99.18	mm/hr

Table C-3. Darcian velocity under Dikes/I-172 combination for 8/13/85 irrigation.

Hours After Irrigation	Location in Plot Top	Bottom
	velocity (mm/h * 10^5)	
1	3.0	17.4
2	3.2	18.3
3	4.3	22.9
4	4.8	23.8
5	5.1	25.2
6	---	----
7	---	----
8	6.1	25.4
9	5.5	23.8
10	---	----
11	5.6	20.3
12	5.1	19.5
13	4.3	17.4
14	4.1	15.4
Average	4.6	20.9

Table C-4. Darcian velocity under Control/I-172 combination for 8/13/85 irrigation.

Hours After Irrigation	Location in Plot Top	Bottom
	velocity (mm/h * 10^5)	
1	4.4	5.1
2	4.5	5.5
3	5.4	9.5
4	6.9	13.2
5	8.1	13.4
6	---	----
7	---	----
8	8.7	12.8
9	8.9	11.8
10	---	----
11	7.1	8.5
12	7.8	7.7
13	6.8	6.5
14	5.8	5.9
Average	6.8	9.1

Table C-5. Darcian velocity under Dikes/D-41 combination for 8/13/85 irrigation.

Hours After Irrigation	Location in Plot Top	Bottom	Top	Bottom
	-------- velocity (mm/h * 10^5) --------			
1	491.5	48.4	-----	-----
2	675.1	62.8	-----	-----
3	1263.8	133.9	-----	-----
4	1563.8	144.6	-----	-----
5	1135.1	180.3	-----	-----
6	------	-----	-----	-----
7	------	-----	-----	-----
8	1102.2	150.0	-----	-----
9	735.6	122.2	-----	-----
10	-----	-----	-----	-----
11	500.1	82.8	120.7	272.0
12	399.8	68.9	-----	-----
13	345.4	49.6	156.5	344.2
14	242.3	32.4	179.2	367.0
15	-----	----	325.6	836.7
16	-----	----	323.1	859.3
17	-----	----	371.9	726.2
18	-----	----	-----	-----
19	-----	----	-----	-----
20	-----	----	325.6	742.0
21	-----	----	286.3	660.1
22	-----	----	-----	-----
23	-----	----	220.7	551.8
24	-----	----	171.6	508.8
25	-----	----	131.2	449.0
26	-----	----	124.5	417.7
Average	768.6	97.8	228.1	561.2

Table C-6. Darcian velocity under Control/D-41 combination for 8/13/85 irrigation.

Hours After Irrigation	Location in Plot Top	Bottom	Bottom
	--- velocity (mm/h * 10^5) ---		
1	0.6	1.6	---
2	0.6	1.7	---
3	1.0	2.4	---
4	1.0	2.4	---
5	1.1	2.8	---
6	---	---	---
7	---	---	---
8	1.2	3.3	---
9	1.2	3.4	---
10	---	---	---
11	1.2	2.8	1.8
12	1.1	2.8	---
13	1.0	2.3	2.0
14	0.8	1.7	2.1
15	---	---	3.2
16	---	---	3.5
17	---	---	3.7
18	---	---	---
19	---	---	---
20	---	---	3.8
21	---	---	3.5
22	---	---	---
23	---	---	2.7
24	---	---	2.5
25	---	---	2.2
26	---	---	2.1
Average	1.0	2.5	2.8

Table C-7. Darcian velocity under Dikes/I-172 combination for 8/15/85 irrigation.

Hours After Irrigation	Location in Plot Top	Bottom
	velocity (mm/h * 10^5)	
1	9.1	23.8
2	10.0	24.5
3	9.6	24.5
4	10.0	25.9
5	10.0	25.5
6	9.6	27.3
7	9.6	29.2
8	9.2	29.6
9	8.8	28.0
10	8.4	29.9
11	8.0	28.0
12	7.2	28.0
13	6.9	26.2
14	6.9	30.2
15	6.9	29.6
Average	8.7	27.3

Table C-8. Darcian velocity under Control/I-172 combination for 8/15/85 irrigation.

Hours After Irrigation	Location in PLot Top	Bottom
	velocity (mm/h * 10^5)	
1	6.9	19.1
2	6.1	17.7
3	5.9	13.3
4	6.0	9.8
5	7.5	9.7
6	6.7	5.6
7	6.3	5.5
8	6.4	5.4
9	6.5	5.5
10	6.3	4.9
11	6.2	4.4
12	5.7	4.4
13	5.1	4.1
14	5.0	4.1
15	5.2	4.1
Average	6.1	7.8

Table C-9. Darcian velocity under Dikes/D-41 combination for 8/15/85 irrigation.

Hours After		Location in Plot		
Irrigation	Top	Bottom	Top	Bottom
	-------- velocity (mm/h * 10^5) -------			
1	171.7	50.2	56.8	121.7
2	252.8	57.9	63.1	128.6
3	270.9	75.7	72.1	137.3
4	303.9	66.4	74.3	136.7
5	403.4	80.7	76.3	127.9
6	327.1	76.2	78.2	127.9
7	350.6	76.2	78.2	120.3
8	316.1	62.8	78.2	120.3
9	316.1	63.3	84.8	119.4
10	264.7	59.3	78.2	119.4
11	275.4	55.4	86.4	127.9
12	275.4	55.4	86.4	127.9
13	220.7	48.2	79.9	136.7
14	247.2	48.2	86.4	145.9
15	247.2	48.2	99.1	165.5
16	-----	----	159.3	199.7
17	-----	----	192.3	212.5
18	-----	----	194.4	212.4
19	-----	----	219.7	225.8
20	-----	----	221.9	226.1
21	-----	----	236.5	255.3
22	-----	----	236.5	240.4
23	-----	----	236.5	255.3
Average	282.9	61.6	125.0	164.8

Table C-10. Darcian velocity under Control/D-41 combination for 8/15/85 irrigation.

Hours After Irrigation	Location in Plot Top	Bottom	Bottom
	---- velocity (mm/h * 10^5) ---		
1	-0.9	1.7	1.1
2	-0.7	1.9	1.1
3	-0.4	2.0	1.1
4	-0.3	1.9	1.1
5	-0.1	2.1	1.2
6	0.0	1.8	1.2
7	0.0	1.8	1.2
8	0.1	1.7	1.0
9	0.1	1.6	1.0
10	0.1	1.5	1.0
11	0.1	1.4	1.0
12	0.1	1.3	0.9
13	0.1	1.2	0.9
14	0.1	1.1	0.9
15	0.1	1.1	0.9
16	---	---	1.2
17	---	---	1.3
18	---	---	1.3
19	---	---	1.4
20	---	---	1.4
21	---	---	1.5
22	---	---	1.5
23	---	---	1.5
Average	-0.1	1.6	1.2

APPENDIX D

Specific research results for
individual water balance variables
and yearly water balance summaries

Table D-1. Total irrigation during analysis periods.

Sprinkler Type	Year 1981	1982	1983	1984	1985	Average
	(8)a	(13)a	(11)a	(12)a	(15)a	(12)a
SPRINKLER STUDY	-------- total irrigation (mm) -------					
I-344	191	277	205	250	---	231
I-172	209	308	263	329	386	299
S-103	---	309	253	327	388	319
D-41	---	---	285	356	408	350
PRIMARY TILLAGE STUDY						
	(8)a	(13)a	(10)a	(12)a	(14)a	(11)a
I-172b	236c	308	237	341	371	314d

a Number of irrigations during analysis period.

b S-41 sprinklers used in 1981.

c Not considered in analysis.

d Based on 1982-1985 data.

Table D-2. Precipitation during analysis periods.

Year	Precipitation (mm)
1981	130
1982	49
1983	133
1984	55
1985	29
Average	79

Table D-3. Total (irrigation plus precipitation) water input during analysis periods.

Sprinkler Type	1981	1982	1983	1984	1985	Average
	(8)a	(13)a	(11)a	(12)a	(15)a	(12)a
SPRINKLER STUDY	------- total water input (mm) --------					
I-344	321	326	338	305	---	323
I-172	339	357	396	384	415	378
S-103	---	358	386	382	417	386
D-41	---	---	418	411	437	422
PRIMARY TILLAGE STUDY						
	(8)a	(13)a	(10)a	(12)a	(14)a	(11)a
I-172b	366c	357	370	396	400	381d

a Number of irrigations during analysis period.

b S-41 sprinklers used in 1981.

c Not considered in analysis.

d Based on 1982-1985 data.

Table D-4. Irrigation runoff during analysis periods.

Primary Tillage	Secondary Tillage	Sprinkler Type	1981	1982	1983	1984	1985	Ave
			Year					
SPRINKLER STUDY			irrigation runoff (mm)					
Disk	IRT	I-344	1	2	2	0	-	1
		I-172	9	10	8	0	4	6
		S-103	-	15	8	1	10	9
		D-41	-	--	30	11	36	26
Disk	Control	I-344	27	39	3	13	--	21
		I-172	52	60	10	23	19	33
		S-103	--	86	66	41	35	57
		D-41	--	--	48	68	55	57
PRIMARY TILLAGE STUDY								
Plow	IRT	I-172a	24b	18	33	5	28	21c
	Control	I-172a	91b	64	59	29	24	44c
Disk	IRT	I-172a	18b	8	5	2	10	6c
	Control	I-172a	63b	34	36	26	21	29c
Till Plant	IRT	I-172a	28b	24	11	8	10	13c
	Control	I-172a	78b	78	52	64	19	53c

a S-41 sprinklers used in 1981.

b Not considered in analysis.

c Based on 1982-1985 data.

Table D-5. Total (irrigation plus precipitation) runoff during analysis periods for sprinkler study.

Primary Tillage	Secondary Tillage	Sprinkler Type	1981	1982	1983	1984	1985	Ave
			---- total runoff (mm) ----					
Disk	IRT	I-344	16	2	8	0	--	6
		I-172	24	10	14	0	4	10
		S-103	--	15	14	1	10	10
		D-41	--	--	36	11	36	28
Disk	Control	I-344	47	39	11	13	--	28
		I-172	72	60	18	23	19	39
		S-103	--	86	74	41	35	59
		D-41	--	--	56	68	55	60
			total runoff (% inputs)					
Disk	IRT	I-344	5	1	2	0	-	2
		I-172	7	3	4	0	1	3
		S-103	-	4	4	0	2	3
		D-41	-	-	9	3	8	7
Disk	Control	I-344	15	12	3	4	-	9
		I-172	21	17	5	6	5	11
		S-103	--	24	19	11	8	16
		D-41	--	--	13	17	13	14

Table D-6. Total (irrigation plus precipitation) runoff during analysis periods for primary tillage study.

Primary Tillage	Secondary Tillage	Sprinkler Type	Year 1981	1982	1983	1984	1985	Ave
			----- total runoff (mm) -----					
Plow	IRT	I-172a	39b	18	39	5	28	23c
	Control	I-172a	111b	64	67	29	24	46c
Disk	IRT	I-172a	35b	8	11	2	10	8c
	Control	I-172a	83b	34	44	26	21	31c
Till Plant	IRT	I-172a	43b	24	17	8	10	15c
		I-172a	98b	78	60	64	19	55c
			total runoff (% inputs)					
Plow	IRT	I-172a	11b	5	11	1	7	6c
	Control	I-172a	30b	18	18	7	6	12c
Disk	IRT	I-172a	9b	2	3	1	3	2c
	Control	I-172a	23b	10	12	7	5	9c
Till Plant	IRT	I-172a	12b	7	5	2	3	4c
	Control	I-172a	27b	22	16	16	5	15c

a S-41 sprinklers used in 1981.

b Not considered in analysis.

c Based on 1982-1985 data.

Table D-8. Ground storage during analysis periods for primary tillage study.

Primary Tillage	Secondary Tillage	Sprinkler Type	1981	1982	1983	1984	1985	Ave
			---- ground storage (mm) ----					
Plow	IRT	I-172a	23b	-23	-21	-58	-24	-32c
	Control	I-172a	- 9b	-70	-60	-100	-23	-63c
Disk	IRT	I-172a	59b	-14	4	-37	21	- 7c
	Control	I-172a	33b	-73	-46	-76	- 1	-49c
Till Plant	IRT	I-172a	62b	-25	-17	-52	24	-18c
	Control	I-172a	23b	-65	-20	-88	12	-40c
			ground storage (% inputs)					
Plow	IRT	I-172a	6b	- 6	- 6	-15	- 6	- 8c
	Control	I-172a	- 2b	-20	-16	-25	- 6	-17c
Disk	IRT	I-172a	16b	- 4	1	- 9	5	- 2c
	Control	I-172a	9b	-20	-12	-19	0	-13c
Till Plant	IRT	I-172a	17b	- 7	- 5	-13	6	- 5c
	Control	I-172a	6b	-18	- 5	-22	3	-11c

a S-41 sprinklers used in 1981.

b Not considered in analysis.

c Based on 1982-1985 data.

Table D-9. Total evapotranspiration during analysis periods for sprinkler study.

Primary Tillage	Secondary Tillage	Sprinkler Type	1981	1982	1983	1984	1985	Ave
					evapotranspiration (mm)			
Disk	IRT	I-344	242	343	341	337	---	316
		I-172	273	401	399	408	378	372
		S-103	---	356	392	396	380	381
		D-41	---	---	398	423	390	404
Disk	Control	I-344	249	325	342	345	---	315
		I-172	258	366	396	424	383	365
		S-103	---	345	369	395	369	370
		D-41	---	---	403	429	390	407
					evapotranspiration (% inputs)			
Disk	IRT	I-344	75	105	101	111	--	98
		I-172	81	112	101	106	91	98
		S-103	--	100	102	104	91	99
		D-41	--	---	95	103	89	96
Disk	Control	I-344	78	100	101	113	--	98
		I-172	76	103	100	110	92	96
		S-103	--	96	96	103	89	96
		D-41	--	--	96	104	89	96

Table D-10. Total evapotranspiration during analysis periods for primary tillage study.

Primary Tillage	Secondary Tillage	Sprinkler Type	1981	1982	1983	1984	1985	Ave
			evapotranspiration (mm)					
Plow	IRT	I-172a	304b	362	352	449	396	390c
	Control	I-172a	264b	363	363	467	399	398c
Disk	IRT	I-172a	274b	363	355	431	369	380c
	Control	I-172a	250b	396	372	446	380	399c
Till Plant	IRT	I-172a	261b	358	370	440	366	384c
	Control	I-172a	245b	344	330	420	369	366c
			evapotranspiration (% inputs)					
Plow	IRT	I-172a	83b	101	95	113	99	102c
	Control	I-172a	72b	102	98	118	100	105c
Disk	IRT	I-172a	75b	102	96	109	92	100c
	Control	I-172a	68b	111	101	113	95	105c
Till Plant	IRT	I-172a	71b	100	100	111	92	101c
	Control	I-172a	67b	96	89	106	92	96c

a S-41 sprinklers used in 1981.

b Not considered in analysis.

c Based on 1982-1985 data.

Table D-11. Average daily evapotranspiration during analysis periods.

Primary Tillage	Secondary Tillage	Sprinkler Type	1981	1982	1983	1984	1985	Ave
SPRINKLER STUDY			daily evapotranspiration (mm)					
Disk	IRT	I-344	5.6	6.1	6.0	6.0	---	5.9
		I-172	6.3	7.2	7.0	7.3	7.7	7.1
		S-103	---	6.4	6.9	7.1	7.8	7.1
		D-41	---	---	7.0	7.6	8.0	7.5
Disk	Control	I-344	5.8	5.8	6.0	6.2	---	6.0
		I-172	6.0	6.5	6.9	7.6	7.8	7.0
		S-103	---	6.2	6.5	7.1	7.5	6.8
		D-41	---	---	7.1	7.7	8.0	7.6
PRIMARY TILLAGE STUDY								
Plow	IRT	I-172a	7.1b	6.5	6.6	8.0	8.4	7.4c
	Control	I-172a	6.1b	6.5	6.8	8.3	8.5	7.5c
Disk	IRT	I-172a	6.4b	6.5	6.7	7.7	7.9	7.2c
	Control	I-172a	5.8b	7.1	7.0	8.0	8.1	7.5c
Till Plant	IRT	I-172a	6.1b	6.4	7.0	7.9	7.8	7.3c
	Control	I-172a	5.7b	6.1	6.2	7.5	7.9	6.9c

a S-41 sprinklers used in 1981.

b Not considered in analysis.

c Based on 1982-1985 data.

Table D-12. Sprinkler study water balance summary for 1981 analysis period.

Primary Tillage	Secondary Tillage	Sprinkler Type	I	+ P	= R	+ GS	+ ET
					(mm)		
Disk	IRT	I-344	191	130	16	63	242
		I-172	209	130	24	42	273
		S-103	---	---	--	--	---
		D-41	---	---	--	--	---
Disk	Control	I-344	191	130	47	25	249
		I-172	209	130	72	9	258
		S-103	---	---	--	-	---
		D-41	---	---	--	-	---
					(% inputs)[a]		
Disk	IRT	I-344	60	40	5	20	75
		I-172	62	38	7	12	81
		S-103	--	--	-	--	--
		D-41	--	--	-	--	--
Disk	Control	I-344	60	40	15	8	78
		I-172	62	38	21	3	76
		S-103	--	--	--	-	--
		D-41	--	--	--	-	--

a Inputs = irrigation + precipitation.

Table D-13. Primary tillage study water balance summary for 1981 analysis period.

Primary Tillage	Secondary Tillage	Sprinkler Type	I	+ P	= R	+ GS	+ ET
			(mm)				
Plow	IRT	S-41	236	130	39	23	304
	Control	S-41	236	130	111	- 9	264
Disk	IRT	S-41	236	130	35	59	274
	Control	S-41	236	130	83	33	250
Till Plant	IRT	S-41	236	130	43	62	261
	Control	S-41	236	130	98	23	245
			(% inputs)[a]				
Plow	IRT	S-41	64	36	11	6	83
	Control	S-41	64	36	30	- 2	72
Disk	IRT	S-41	64	36	9	16	75
	Control	S-41	64	36	23	9	68
Till Plant	IRT	S-41	64	36	12	17	71
	Control	S-41	64	36	27	6	67

a Inputs = irrigation + precipitation.

Table D-14. Sprinkler study water balance summary for 1982 analysis period.

Primary Tillage	Secondary Tillage	Sprinkler Type	I	+ P	= R	+ GS	+ ET
			(mm)				
Disk	IRT	I-344	277	49	2	-19	343
		I-172	308	49	10	-54	401
		S-103	309	49	15	-13	356
		D-41	---	--	--	--	---
Disk	Control	I-344	277	49	39	-38	325
		I-172	308	49	60	-69	366
		S-103	309	49	86	-73	345
		D-41	---	--	--	--	---
			(% inputs)[a]				
Disk	IRT	I-344	85	15	1	- 6	105
		I-172	86	14	3	-15	112
		S-103	86	14	4	- 4	100
		D-41	--	--	-	--	---
Disk	Control	I-344	85	15	12	-12	100
		I-172	86	14	17	-19	103
		S-103	86	14	24	-20	96
		D-41	--	--	--	--	--

a Inputs = irrigation + precipitation.

Table D-15. Primary tillage study water balance summary for 1982 analysis period.

Primary Tillage	Secondary Tillage	Sprinkler Type	I	+ P	= R	+ GS	+ ET
			(mm)				
Plow	IRT	I-172	308	49	18	-23	362
	Control	I-172	308	49	64	-70	363
Disk	IRT	I-172	308	49	8	-14	363
	Control	I-172	308	49	34	-73	396
Till Plant	IRT	I-172	308	49	24	-25	358
	Control	I-172	308	49	78	-65	344
			(% inputs)[a]				
Plow	IRT	I-172	86	14	5	- 6	101
	Control	I-172	86	14	18	-20	102
Disk	IRT	I-172	86	14	2	- 4	102
	Control	I-172	86	14	10	-20	111
Till Plant	IRT	I-172	86	14	7	- 7	100
	Control	I-172	86	14	22	-18	96

a Inputs = irrigation + precipitation.

Table D-16. Sprinkler study water balance summary for 1983 analysis period.

Primary Tillage	Secondary Tillage	Sprinkler Type	I	+ P	= R	+ GS	+ ET
			(mm)				
Disk	IRT	I-344	205	133	8	-11	341
		I-172	263	133	14	-17	399
		S-103	253	133	14	-20	392
		D-41	285	133	36	-16	398
Disk	Control	I-344	205	133	11	-15	342
		I-172	263	133	18	-18	396
		S-103	253	133	74	-57	369
		D-41	285	133	56	-41	403
			(% inputs)[a]				
Disk	IRT	I-344	61	39	2	- 3	101
		I-172	66	34	4	- 4	101
		S-103	66	34	4	- 5	102
		D-41	68	32	9	- 4	95
Disk	Control	I-344	61	39	3	- 4	101
		I-172	66	34	5	- 5	100
		S-103	66	34	19	-15	96
		D-41	68	32	13	-10	96

a Inputs = irrigation + precipitation.

Table D-17. Primary tillage study water balance summary for 1983 analysis period.

Primary Tillage	Secondary Tillage	Sprinkler Type	I	+ P	= R	+ GS	+ ET
			(mm)				
Plow	IRT	I-172	237	133	39	-21	352
	Control	I-172	237	133	67	-60	363
Disk	IRT	I-172	237	133	11	4	355
	Control	I-172	237	133	44	-46	372
Till Plant	IRT	I-172	237	133	17	-17	370
	Control	I-172	237	133	60	-20	330
			(% inputs)[a]				
Plow	IRT	I-172	64	36	11	- 6	95
	Control	I-172	64	36	18	-16	98
Disk	IRT	I-172	64	36	3	1	96
	Control	I-172	64	36	12	-12	101
Till Plant	IRT	I-172	64	36	5	- 5	100
	Control	I-172	64	36	16	- 5	89

a Inputs = irrigation + precipitation.

Table D-18. Sprinkler study water balance summary for 1984 analysis period.

Primary Tillage	Secondary Tillage	Sprinkler Type	I	+ P	= R	+ GS	+ ET
			----------		(mm)	----------	
Disk	IRT	I-344	250	55	0	-32	337
		I-172	329	55	0	-24	408
		S-103	327	55	1	-15	396
		D-41	356	55	11	-23	423
Disk	Control	I-344	250	55	13	-53	345
		I-172	329	55	23	-63	424
		S-103	327	55	41	-54	395
		D-41	356	55	68	-86	429
			------		(% inputs)[a]	-------	
Disk	IRT	I-344	82	18	0	-10	111
		I-172	86	14	0	- 6	106
		S-103	86	14	0	- 4	104
		D-41	87	13	3	- 6	103
Disk	Control	I-344	82	18	4	-17	113
		I-172	86	14	6	-16	110
		S-103	86	14	11	-14	103
		D-41	87	13	17	-18	102

a Inputs = irrigation + precipitation.

Table D-19. Primary tillage study water balance summary for 1984 analysis period.

Primary Tillage	Secondary Tillage	Sprinkler Type	I	+ P	= R	± GS	± ET
			(mm)				
Plow	IRT	I-172	341	55	5	-58	449
	Control	I-172	341	55	29	-100	467
Disk	IRT	I-172	341	55	2	-37	431
	Control	I-172	341	55	26	-76	446
Till Plant	IRT	I-172	341	55	8	-52	440
	Control	I-172	341	55	64	-88	417
			(% inputs)[a]				
Plow	IRT	I-172	86	14	1	-15	113
	Control	I-172	86	14	7	-25	118
Disk	IRT	I-172	86	14	1	- 9	109
	Control	I-172	86	14	7	-19	113
Till Plant	IRT	I-172	86	14	2	-13	111
	Control	I-172	86	14	16	-22	106

a Inputs = irrigation + precipitation.

Table D-20. Sprinkler study water balance summary for 1985 analysis period.

Primary Tillage	Secondary Tillage	Sprinkler Type	I	+ P	= R	+ GS	+ ET
			(mm)				
Disk	IRT	I-344	---	--	-	--	---
		I-172	386	29	4	33	378
		S-103	388	29	10	27	380
		D-41	408	29	36	11	390
Disk	Control	I-344	---	--	-	--	---
		I-172	386	29	19	13	383
		S-103	388	29	35	13	369
		D-41	408	29	55	-8	390
			(% inputs)[a]				
Disk	IRT	I-344	--	-	-	-	--
		I-172	93	7	1	8	91
		S-103	93	7	2	7	91
		D-41	93	7	8	3	89
Disk	Control	I-344	--	-	-	-	--
		I-172	93	7	5	3	92
		S-103	93	7	8	3	89
		D-41	93	7	13	-2	89

a Inputs = irrigation + precipitation.

Table D-21. Primary tillage study water balance summary for 1985 analysis period.

Primary Tillage	Secondary Tillage	Sprinkler Type	I +	P =	R +	GS +	ET
			(mm)				
Plow	IRT	I-172	371	29	28	-24	396
	Control	I-172	371	29	24	-23	399
Disk	IRT	I-172	371	29	10	21	369
	Control	I-172	371	29	21	- 1	380
Till Plant	IRT	I-172	371	29	10	24	366
	Control	I-172	371	29	19	12	369
			(% inputs)[a]				
Plow	IRT	I-172	93	7	7	- 6	99
	Control	I-172	93	7	6	- 6	100
Disk	IRT	I-172	93	7	3	5	92
	Control	I-172	93	7	5	0	95
Till Plant	IRT	I-172	93	7	3	6	92
	Control	I-172	93	7	5	3	92

a Inputs = irrigation + precipitation.

APPENDIX E

Raw data used for statistical analysis

Table E-1. Raw data used for statistical analysis.

Primary Tillage	Secondary Tillage	Sprinkler Type	Year	Rep	I+P	R	GS	ET
					depth values (mm)			
Sprinkler Study								
Disk	IRT	I-344	1981	1	321	15.8	60.6	242
				2	.	16.9	65.3	.
			1982	1	326	3.6	-24.1	343
				2	.	1.8	- 8.1	.
				3	.	0.3	-23.9	.
			1983	1	338	8.1	-20.8	341
				2	.	8.0	3.3	.
				3	.	7.7	-16.1	.
			1984	1	305	0	-28.5	337
				2	.	0	-32.7	.
				3	.	0	-43.6	.
				4	.	0	-24.5	.
Disk	IRT	I-172	1981	1	339	17.5	42.0	273
				2	.	30.9	MD[a]	.
			1982	1	357	1.9	-13.3	401
				2	.	19.1	-62.5	.
				3	.	11.0	-85.2	.
			1983	1	396	8.3	-19.2	399
				2	.	16.4	-26.1	.
				3	.	15.6	- 6.9	.
			1984	1	384	0	-28.6	408
				2	.	0	- 9.3	.
				3	.	0	-36.9	.
				4	.	0	-48.6	.
				5	.	0	-12.0	.
				6	.	0	-10.8	.
			1985	1	415	13.0	56.3	378
				2	.	0	53.0	.
				3	.	1.1	9.7	.
				4	.	0	15.5	.
				5	.	1.7	29.6	.
				6	.	6.7	MD[a]	.
Disk	IRT	S-103	1982	1	358	14.7	-21.1	356
				2	.	14.4	- 4.9	.
				3	.	16.4	-12.9	.
			1983	1	386	16.5	- 9.8	392
				2	.	10.4	-25.8	.
				3	.	14.0	-24.6	.
			1984	1	382	1.7	- 2.1	396
				2	.	1.0	- 2.6	.
				3	.	0	- 9.5	.

Table E-1. Continued.

Primary Tillage	Secondary Tillage	Sprinkler Type	Year	Rep	I+P	R	GS	ET
					depth values (mm)			
Disk	IRT	S-103	1984	4	382	1.0	-27.6	396
				5	.	0	-39.8	.
				6	.	0	- 9.0	.
			1985	1	417	9.3	2.0	380
				2	.	6.4	46.4	.
				3	.	3.9	33.9	.
				4	.	23.2	20.2	.
				5	.	9.4	25.1	.
				6	.	4.9	36.7	.
Disk	IRT	D-41	1983	1	418	50.1	-37.4	398
				2	.	37.1	- 4.5	.
				3	.	21.3	- 4.7	.
			1984	1	411	15.4	-22.4	423
				2	.	2.5	-34.4	.
				3	.	16.1	-18.9	.
				4	.	16.3	-35.3	.
				5	.	1.7	-12.1	.
				6	.	21.7	-13.1	.
			1985	1	437	43.2	-26.5	390
				2	.	47.8	-19.4	.
				3	.	39.1	15.6	.
			1985	4	.	38.5	47.2	.
				5	.	18.2	6.1	.
				6	.	27.0	41.5	.
Disk	Control	I-344	1981	1	321	57.3	26.0	249
				2	.	35.7	24.8	.
			1982	1	326	32.4	-48.1	325
				2	.	50.4	-29.6	.
				3	.	34.6	-35.1	.
			1983	1	338	11.4	-10.2	342
				2	.	8.0	-15.9	.
				3	.	14.2	-17.3	.
			1984	1	305	7.5	70.4	345
				2	.	18.0	36.1	.
Disk	Control	I-172	1981	1	339	60.0	- 4.1	258
				2	.	84.8	22.1	.
			1982	1	357	35.9	-68.9	366
				2	.	73.4	MD[a]	.
				3	.	71.5	MD[a]	.
			1983	1	396	19.4	-23.4	396
				2	.	14.1	- 9.0	.
				3	.	MD[a]	-22.2	.

Table E-1. Continued.

Primary Tillage	Secondary Tillage	Sprinkler Type	Year	Rep	I+P	R	GS	ET
					depth values (mm)			
Disk	Control	I-172	1984	1	384	16.7	-69.1	424
				2	.	19.6	-78.9	.
				3	.	34.9	-40.6	.
			1985	1	415	30.3	1.1	383
				2	.	12.4	26.5	.
				3	.	13.5	10.2	.
Disk	Control	S-103	1982	1	358	77.0	-74.2	345
				2	.	81.9	-87.0	.
				3	.	98.7	-58.3	.
			1983	1	386	66.9	-44.3	369
				2	.	83.7	-69.9	.
				3	.	72.8	-57.4	.
			1984	1	382	36.9	-76.8	395
				2	.	28.2	-28.6	.
				3	.	58.4	-56.0	.
			1985	1	417	43.0	-26.2	369
				2	.	37.6	39.1	.
				3	.	25.3	25.8	.
Disk	Control	D-41	1983	1	418	66.3	-66.2	403
				2	.	51.7	-32.4	.
				3	.	50.2	-23.5	.
			1984	1	411	62.0	-70.1	429
				2	.	68.9	-101.8	.
				3	.	73.6	MD[a]	.
			1985	1	437	57.6	-22.5	390
				2	.	47.1	-10.8	.
				3	.	61.2	10.3	.
Primary Tillage Study								
Plow	IRT	I-172	1982	1	357	25.0	-11.4	362
				2	.	22.7	-33.1	.
				3	.	6.6	-24.9	.
			1983	1	370	34.2	- 4.3	352
				2	.	43.9	-28.8	.
				3	.	MD[a]	-31.0	.
			1984	1	396	5.3	-62.4	449
				2	.	5.5	-59.3	.
				3	.	2.9	-53.3	.
			1985	1	400	16.8	-42.3	396
				2	.	42.9	- 5.0	.
				3	.	24.7	MD[a]	.
Plow	Control	I-172	1982	1	357	54.2	-76.3	363
				2	.	80.0	-74.5	.

Table E-1. Continued.

Primary Tillage	Secondary Tillage	Sprinkler Type	Year	Rep	I+P	R	GS	ET
					depth values (mm)			
Plow	Control	I-172	1982	3	357	56.8	-60.5	363
			1983	1	370	64.0	-77.7	363
				2	.	81.1	-59.3	.
				3	.	54.4	-41.4	.
			1984	1	396	38.8	-98.3	467
				2	.	23.3	-80.5	.
				3	.	24.7	-122.3	.
			1985	1	400	29.8	-15.2	399
				2	.	23.5	-31.8	.
				3	.	17.3	-20.6	.
Disk	IRT	I-172	1982	1	357	13.1	- 2.6	363
				2	.	6.0	- 8.2	.
				3	.	6.3	-30.2	.
			1983	1	370	13.9	8.6	355
				2	.	8.7	- 3.7	.
				3	.	10.9	5.6	.
			1984	1	396	0	-41.0	431
				2	.	3.6	-54.6	.
				3	.	1.3	-15.8	.
			1985	1	400	7.6	38.6	369
				2	.	14.4	13.0	.
				3	.	7.0	11.5	.
Disk	Control	I-172	1982	1	357	26.5	-61.8	396
				2	.	36.9	-89.4	.
				3	.	38.7	-67.6	.
			1983	1	370	34.8	-22.1	372
				2	.	72.2	-60.7	.
				3	.	24.3	-55.6	.
			1984	1	396	28.8	-50.1	446
				2	.	24.2	-84.0	.
				3	.	26.1	-95.2	.
			1985	1	400	24.9	22.0	380
				2	.	28.0	-18.3	.
				3	.	8.6	- 5.3	.
Till Plant	IRT	I-172	1982	1	357	17.0	-13.8	358
				2	.	18.4	-35.3	.
				3	.	36.7	MD[a]	.
			1983	1	370	11.4	- 7.7	370
				2	.	8.0	-40.5	.
				3	.	32.9	- 4.1	.
			1984	1	396	1.8	-36.9	440
				2	.	6.7	-67.6	.

Table E-1. Continued.

Primary Tillage	Secondary Tillage	Sprinkler Type	Year	Rep	I+P	R	GS	ET
					depth values (mm)			
Till Plant	IRT	I-172	1984	3	396	16.3	MD[a]	440
			1985	1	400	9.5	53.9	366
				2	.	6.5	-20.6	.
				3	.	13.9	39.5	.
Till Plant	Control	I-172	1982	1	357	83.3	-43.3	344
				2	.	76.8	-91.1	.
				3	.	73.0	-61.5	.
			1983	1	370	47.5	-11.0	330
				2	.	69.5	-37.3	.
				3	.	MD[a]	-11.3	.
			1984	1	396	64.6	-74.0	420
				2	.	58.0	-91.0	.
				3	.	68.8	-98.9	.
			1985	1	400	16.7	7.8	369
				2	.	31.4	- 1.9	.
				3	.	7.5	28.9	.

a Missing data.

APPENDIX F

Specific research results for
economic analysis variables

Table F-1. Grain yields at 15.5% moisture.

Primary Tillage	Secondary Tillage	Sprinkler Type	1981	1982	1983	1984	1985	Ave
			Year					
SPRINKLER STUDY			---- grain yields (t/ha) ----					
Disk	IRT	I-344	12.2	12.7	12.5	12.0	----	12.4
		I-172	14.2	12.7	12.6	11.4	9.9	12.2
		S-103	----	12.9	10.6	11.0	10.5	11.3
		D-41	----	----	12.2	11.6	10.5	11.4
Disk	Control	I-344	13.2	11.9	12.3	12.4	----	12.5
		I-172	14.4	12.4	12.3	11.8	10.3	12.2
		S-103	----	12.3	11.0	11.8	10.4	11.4
		D-41	----	----	10.9	11.8	9.9	10.9
PRIMARY TILLAGE STUDY								
Plow	IRT	I-172a	11.6	12.2	12.0	11.2	9.3	11.2b
	Control	I-172a	10.4	11.8	11.2	11.4	10.5	11.2b
Disk	IRT	I-172a	12.0	12.7	12.3	12.0	10.3	11.8b
	Control	I-172a	11.6	12.4	10.6	11.8	10.3	11.3b
Till Plant	IRT	I-172a	12.0	12.7	11.8	12.6	10.8	12.0b
	Control	I-172a	12.2	12.7	11.5	11.2	11.1	11.6b

a S-41 sprinklers used in 1981.

b Based on 1982-1985.

Table F-2. Total irrigation depth at canopy top during analysis periods.

Sprinkler Type	1982	1983	Year 1984	1985	Average
SPRINKLER STUDY	total irr. depth at canopy (mm)				
I-344	277	205	250	300a	258
I-172	308	263	329	386	322
S-103	309	253	327	388	319
D-41	340a	285	356	408	347
PRIMARY TILLAGE STUDY					
I-172	308	237	341	371	314

a Estimated value.

Table F-3. Irrigation runoff during analysis periods.

Primary Tillage	Secondary Tillage	Sprinkler Type	Year 1982	1983	1984	1985	Ave
SPRINKLER STUDY			irrigation runoff (mm)				
Disk	IRT	I-344	2	2	0	0a	1
		I-172	10	8	0	4	6
		S-103	15	8	1	10	9
		D-41	40a	30	11	36	29
Disk	Control	I-344	39	3	13	11a	17
		I-172	60	10	23	19	28
		S-103	86	66	41	35	57
		D-41	100a	48	68	55	68
PRIMARY TILLAGE STUDY							
Plow	IRT	I-172	18	33	5	28	21
	Control	I-172	64	59	29	24	44
Disk	IRT	I-172	8	5	2	10	6
	Control	I-172	34	36	26	21	29
Till Plant	IRT	I-172	24	11	8	10	13
	Control	I-172	78	52	64	19	53

a Estimated value.

Table F-4. Irrigation water available for crop use.[a]

Primary Tillage	Secondary Tillage	Sprinkler Type	1982	1983	1984	1985	Ave
SPRINKLER STUDY			available water (mm)				
Disk	IRT	I-344	275	203	250	300b	257
		I-172	298	255	329	382	316
		S-103	294	245	326	378	311
		D-41	300b	255	345	372	318
Disk	Control	I-344	238	202	237	289b	242
		I-172	248	253	306	367	294
		S-103	223	187	286	353	262
		D-41	240b	237	288	353	280
PRIMARY TILLAGE STUDY							
Plow	IRT	I-172	290	204	336	343	293
	Control	I-172	244	178	312	347	270
Disk	IRT	I-172	300	232	339	361	308
	Control	I-172	274	201	315	350	285
Till Plant	IRT	I-172	284	226	333	361	301
	Control	I-172	230	185	277	352	261

a "D" variable of Equation 8.

b Based on estimated irrigation depth and runoff.

Table F-5. Irrigation runoff as a percent of irrigation water reaching the canopy.

Primary Tillage	Secondary Tillage	Sprinkler Type	Year 1982	1983	1984	1985	Ave
SPRINKLER STUDY			irr. runoff (% canopy)				
Disk	IRT	I-344	1	1	0	0a	1
		I-172	3	3	0	1	2
		S-103	5	3	0	3	3
		D-41	12a	11	3	9	9
Disk	Control	I-344	14	1	5	4a	6
		I-172	19	4	7	5	9
		S-103	28	26	13	9	19
		D-41	29a	17	19	13	20
PRIMARY TILLAGE STUDY							
Plow	IRT	I-172	6	14	1	8	7
	Control	I-172	21	25	9	6	15
Disk	IRT	I-172	3	2	1	3	2
	Control	I-172	11	15	8	6	10
Till Plant	IRT	I-172	8	5	2	3	5
	Control	I-172	25	22	19	5	18

a Based on estimated irrigation depth and runoff.

Table F-6. Irrigation efficiency.[a]

Primary Tillage	Secondary Tillage	Sprinkler Type	1982	1983	1984	1985	Ave
SPRINKLER STUDY			irr. efficiency (%)				
Disk	IRT	I-344	79	79	80	80b	80
		I-172	87	87	90	89	88
		S-103	85	87	90	87	87
		D-41	83b	84	92	86	86
Disk	Control	I-344	66	79	75	76b	74
		I-172	71	86	83	85	81
		S-103	62	64	77	81	71
		D-41	66b	78	76	82	76
PRIMARY TILLAGE STUDY							
Plow	IRT	I-172	84	76	89	82	83
	Control	I-172	69	65	81	84	75
Disk	IRT	I-172	87	88	89	87	88
	Control	I-172	79	75	82	84	80
Till Plant	IRT	I-172	82	85	88	87	86
	Control	I-172	65	68	71	85	72

a Irrigation efficiency = percent of gross irrigation available for crop use. Assumed spray losses = I-344, 20%; I-172 and S-103, 10%; D-41 and S-41, 5%.

b Based on estimated irrigation depth and runoff.

Table F-7. Diesel fuel requirement for field operations from Griffith and Parsons (1981).

Operations	Soil Draft Ratings Low	Moderate	High
	fuel requirement (L/ha)[a]		
Shredding cornstalks	7.02	7.02	7.02
Subsoil chiseling, 35.6 cm	12.16	19.64	27.59
Moldboard plowing, 20.3 cm	10.76	17.30	24.32
Chiseling, 20.3 cm	7.02	11.69	16.37
Offset disking	5.61	8.89	12.63
Field cultivating, plowed ground	5.14	5.61	6.08
Tandem disking, plowed ground	4.68	5.14	5.61
Tandem disking, 2nd trip	4.21	4.68	5.14
Tandem disking, cornstalks	3.74	4.21	4.68
Forming ridges, fall	3.74	4.21	4.68
Harrowing, spring tooth	3.27	3.74	4.21
Harrowing, spike tooth	3.27	3.27	3.27
NH_3 application, no-till ground	6.08	9.82	13.56
NH_3 application, plowed ground	5.61	6.55	7.48
Field cultivating + planter	8.89	9.82	10.76
Strip rotary till + planter	7.95	8.89	9.82
Planting, wheel track	5.61	6.08	6.55
Planting, conventional	3.74	4.68	5.61
Planting, till	3.74	4.68	5.61
Planting, no-till	3.74	4.68	5.61
Cultivating, disk hiller	3.27	3.74	4.21
Cultivating, sweeps	2.81	3.27	3.74
Cultivating, rolling tines	2.81	3.27	3.74
Rotary hoeing	2.34	2.34	2.34
Spraying fertilizer	1.87	1.87	1.87
Spraying pesticides	1.40	1.40	1.40

a Fuel requirements given are averages of tests conducted over a wide range of soils. The actual fuel requirements for a particular field operation in a particular soil type may vary as much as 25 percent or more from the values given. Soil types associated with the draft ratings include: Low = sands and sandy loams; Moderate = loams and silt loams; High = clay loams and clays. To convert diesel to gasoline equivalent, multiply by 1.4.

Table F-8. Diesel fuel requirement for the tillage sequences used.[a]

Tillage Sequence	Fuel Req. (L/ha)
Disk, Plant, Cultivate, IRT	20.5b
Disk, Plant, Cultivate	12.2
Plow, Disk, Plant, Cultivate, IRT	38.7b
Plow, Disk, Plant, Cultivate	30.4
Till-Plant, Cultivate, IRT	16.3b
Till-Plant, Cultivate	8.0

a Based on Griffith and Parsons (1981).

b Calculated IRT fuel requirement = 8.3 L/ha.

APPENDIX G

Listing of economic analysis program

```
1000 DIM VAR$(10), UVAR$(10), VAR1(10), VAR2(10),
PUMPCON(2)
1005 DIM VARIAB$(4), UVARIAB$(4), COST(4), R(4), PVF(4)
1010 DIM CD(3), C1(3), C2(3), PW(3), SECNAME$(3)
1015 CLS
1020 PRINT : PRINT : PRINT TAB(7);
1025 PRINT "THIS PROGRAM ANALYZES THE VARIABLES OF PUMPING
COST, TILLAGE COST"
1030 PRINT : PRINT TAB(7);
1035 PRINT "AND CROP YIELD.  ANNUAL COSTS OF PUMPING AND
TILLAGE AND ANNUAL"
1040 PRINT : PRINT TAB(7);
1045 PRINT "INCOME FROM THE CROP YIELD ARE CALCULATED.  A
PRICE VARIATION"
1050 PRINT : PRINT TAB(7);
1055 PRINT "FACTOR, ACCOUNTING FOR INTEREST RATE, ANALYSIS
PERIOD AND ANY"
1060 PRINT : PRINT TAB(7);
1065 PRINT "PRICE VARIATION DURING THE ANALYSIS PERIOD, IS
USED TO CONVERT"
1070 PRINT : PRINT TAB(7);
1075 PRINT "ANNUAL COSTS TO UNIFORM ANNUAL COSTS."
1080 PRINT : PRINT : PRINT : PRINT : PRINT : PRINT TAB(7);
1085 PRINT "PRESS ANY KEY TO CONTINUE.  ";
1090 ANS$ = INPUT$(1) : PRINT
1095 CLS
1100 PRINT : PRINT : PRINT TAB(7);
1105 PRINT "UNIFORM ANNUAL COSTS ARE USED TO DETERMINE THE
ECONOMIC FEASI-"
1110 PRINT : PRINT TAB(7);
1115 PRINT "BILITY OF MODIFICATIONS IN THE IRRIGATION
SYSTEM AND/OR TILLAGE"
1120 PRINT : PRINT TAB(7);
1125 PRINT "PRACTICES.  THE UNIFORM ANNUAL COST
DIFFERENCE, PRODUCED BY THE"
1130 PRINT : PRINT TAB(7);
1135 PRINT "CHANGE(S), IS CONVERTED TO A PRESENT WORTH
VALUE USING A UNIFORM"
1140 PRINT : PRINT TAB(7);
1145 PRINT "SERIES AMORTIZATION FACTOR.  THE PRESENT WORTH
VALUE REPRESENTS"
1150 PRINT : PRINT TAB(7);
1155 PRINT "THE MAXIMUM AMOUNT THAT BE PROFITABLY INVESTED
ON SYSTEM"
1160 PRINT : PRINT TAB(7);
1165 PRINT "MODIFICATION."
1170 PRINT : PRINT : PRINT : PRINT : PRINT : PRINT TAB(7);
1175 PRINT "PRESS ANY KEY TO CONTINUE.  ";
1180 ANS$ = INPUT$(1) : PRINT
1185 CLS
```

```
1190 PRINT : PRINT : PRINT TAB(7);
1195 PRINT "WHAT INTEREST RATE WILL BE USED FOR THIS
ANALYSIS (%)?  ";
1200 INPUT "", I
1205 PRINT : PRINT : PRINT TAB(7);
1210 PRINT "WHAT LENGTH OF TIME WILL BE USED FOR THIS
ANALYSIS (YEARS)?  ";
1215 INPUT "", Y
1220 AF = (1 - (1 + I/100)^-Y) / (I/100)
1225 W = 0
1230 GOSUB 4295
1235 SECNUM = 1
1240 VARYT$ = "ENERGY TYPE"
1245 VARYC$ = "ENERGY COST"
1250 SECNAME$(SECNUM) = "PUMPING COST"
1255 GOSUB 4270
1260 PRINT "PUMPING COST DEPENDS ON IRRIGATED AREA, STATIC
LIFT, FRICTION"
1265 PRINT TAB(7);
1270 PRINT "AND MINOR LOSSES IN THE DELIVERY SYSTEM,
SYSTEM PRESSURE, YEARLY"
1275 PRINT TAB(7);
1280 PRINT "APPLICATION DEPTH, PUMPING PLANT EFFICIENCY,
SPRAY LOSS, RUNOFF,"
1285 PRINT TAB(7);
1290 PRINT "DEEP PERCOLATION AND ENERGY COSTS."
1295 PRINT : PRINT : PRINT TAB(7)
1300 PRINT "DO YOU WISH TO CALCULATE PUMPING COST (Y/N)?
";
1305 LINE INPUT "", ANS$
1310 IF ANS$ = "Y" OR ANS$ = "y"  THEN 1325
1315 IF ANS$ = "N" OR ANS$ = "n"  THEN 2295
1320 GOSUB 4350 : GOTO 1300
1325 N = 10
1330 VAR$(1) = "IRRIGATED AREA"
1335 VAR$(2) = "STATIC LIFT"
1340 VAR$(3) = "FRICTION AND MINOR LOSS"
1345 VAR$(4) = "SYSTEM PRESSURE"
1350 VAR$(5) = "TOTAL APPLICATION DEPTH"
1355 VAR$(6) = "PUMPING PLANT EFFICIENCY"
1360 VAR$(7) = "SPRAY LOSS"
1365 VAR$(8) = "RUNOFF"
1370 VAR$(9) = "DEEP PERCOLATION"
1375 VAR$(10) = "IRRIGATION EFFICIENCY"
1380 IF W = 1  THEN 1415
1385 UVAR$(1) = "(AC)"
1390 UVAR$(2) = "(FT)"
1395 UVAR$(3) = "(FT)"
1400 UVAR$(4) = "(PSI)"
1405 UVAR$(5) = "(IN)"
```

```
1410 GOTO 1440
1415 UVAR$(1) = "(HA)"
1420 UVAR$(2) = "(M)"
1425 UVAR$(3) = "(M)"
1430 UVAR$(4) = "(KPA)"
1435 UVAR$(5) = "(MM)"
1440 UVAR$(6) = "(%)"
1445 UVAR$(7) = "(%)"
1450 UVAR$(8) = "(%)"
1455 UVAR$(9) = "(%)"
1460 UVAR$(10) = "(%)"
1465 GOSUB 4370
1470 CLS
1475 PRINT : PRINT : PRINT TAB(7);
1480 Z = 0
1485 PRINT "TYPE THE LETTER CORRESPONDING TO THE ENERGY
CURRENTLY USED BY"
1490 PRINT TAB(7);
1495 PRINT "YOUR IRRIGATION SYSTEM."
1500 PRINT : PRINT TAB(12);
1505 IF VARIAB$(1) = "ELECTRICITY"  THEN 1525
1510 PRINT "E = ELECTRICITY"
1515 PRINT TAB(12);
1520 IF VARIAB$(1) = "DIESEL FUEL"  THEN 1540
1525 PRINT "D = DIESEL FUEL"
1530 PRINT TAB(12);
1535 IF VARIAB$(1) = "GASOLINE"  THEN 1545
1540 PRINT "G = GASOLINE"
1545 LINE INPUT "", ANS$
1550 Z = Z + 1
1555 CLS
1560 PRINT : PRINT : PRINT TAB(7);
1565 IF ANS$ = "E" OR ANS$ = "e"  THEN 1585
1570 IF ANS$ = "D" OR ANS$ = "d"  THEN 1620
1575 IF ANS$ = "G" OR ANS$ = "g"  THEN 1660
1580 GOSUB 4350 : GOTO 1485
1585 VARIAB$(Z) = "ELECTRICITY"
1590 UVARIAB$(Z) = "(CENTS/KWH)"
1595 IF W = 1  THEN 1610
1600 PUMPCON(Z) = .0853
1605 GOTO 1695
1610 PUMPCON(Z) = .0272
1615 GOTO 1695
1620 VARIAB$(Z) = "DIESEL FUEL"
1625 IF W = 1  THEN 1645
1630 UVARIAB$(Z) = "(CENTS/GAL)"
1635 PUMPCON(Z) = .00215
1640 GOTO 1695
1645 UVARIAB$(Z) = "(CENTS/L)"
1650 PUMPCON(Z) = .0026
```

```
1655 GOTO 1695
1660 VARIAB$(Z) = "GASOLINE"
1665 IF W = 1  THEN 1685
1670 UVARIAB$(Z) = "(CENTS/GAL)"
1675 PUMPCON(Z) = .00234
1680 GOTO 1695
1685 UVARIAB$(Z) = "(CENTS/L)"
1690 PUMPCON(Z) = .00283
1695 PRINT "WHAT IS THE COST OF ";VARIAB$(Z);"
";UVARIAB$(Z);"?  ";
1700 INPUT "",COST(Z)
1705 GOSUB 4125
1710 IF Z = 2  THEN 1800
1715 PRINT "WILL THE  ";VARYT$;" CHANGE (Y/N)?  ";
1720 LINE INPUT "", ANS$
1725 IF ANS$ = "Y" OR ANS$ = "y"  THEN 1740
1730 IF ANS$ = "N" OR ANS$ = "n"  THEN 1770
1735 GOSUB 4350 : GOTO 1715
1740 CLS
1745 PRINT : PRINT : PRINT TAB(7);
1750 PRINT "TYPE THE LETTER CORRESPONDING TO THE NEW
ENERGY THAT WILL BE USED"
1755 PRINT TAB(7);
1760 PRINT "BY YOUR IRRIGATION SYSTEM."
1765 GOTO 1500
1770 PUMPCON(2) = PUMPCON(1)
1775 UVARIAB$(2) = UVARIAB$(1)
1780 VARIAB$(2) = VARIAB$(1)
1785 COST(2) = COST(1)
1790 R(2) = R(1)
1795 PVF(2) = PVF(1)
1800 CLS
1805 PRINT : PRINT : PRINT TAB(7);
1810 VARIAB$(3) = "DEMAND CHARGE"
1815 VARIAB$(4) = "DEMAND CHARGE"
1820 Z = 3
1825 IF VARIAB$(1)  "ELECTRICITY"  THEN 1890
1830 PRINT "WHAT IS THE CURRENT TOTAL ELECTRICAL DEMAND
CHARGE ($)?  ";
1835 INPUT "", DC1
1840 IF DC1 = 0  THEN 1890
1845 GOSUB 4125
1850 IF VARIAB$(2)  "ELECTRICITY"  THEN 1960
1855 PRINT TAB(7);
1860 PRINT "WILL THE DEMAND CHARGE CHANGE (Y/N)?  ";
1865 LINE INPUT "", ANS$
1870 PRINT : PRINT : PRINT TAB(7);
1875 IF ANS$ = "Y" OR ANS$ = "y"  THEN 1910
1880 IF ANS$ = "N" OR ANS$ = "n"  THEN 1940
1885 GOSUB 4350 : GOTO 1860
```

```
1890 DC1 = 0 : R(3) = 0 : PVF(3) = 1
1895 PRINT : PRINT : GOTO 1855
1900 IF VARIAB$(2)  "ELECTRICITY"  THEN 1960
1905 PRINT TAB(7);
1910 PRINT "WHAT WILL BE THE NEW TOTAL ELECTRICAL DEMAND
CHARGE ($)?  ";
1915 INPUT "", DC2
1920 IF DC2 = 0  THEN 1960
1925 Z = Z + 1
1930 GOSUB 4125
1935 GOTO 1965
1940 DC2 = DC1
1945 R(4) = R(3)
1950 PVF(4) = PVF(3)
1955 GOTO 1965
1960 DC2 = 0 : R(4) = 0 : PVF(4) = 1
1965 GOSUB 4565
1970 PRINT : PRINT TAB(7);
1975 IF DC1 = 0  AND DC2 = 0  THEN 2065
1980 IF DC1 = 0  AND DC2  0  THEN 2005
1985 PRINT "CURRENT TOTAL ELECTRICAL DEMAND CHARGE ($) =
";
1990 PRINT USING "#####.##"; DC1
1995 IF DC2 = 0  THEN 2015
2000 PRINT TAB(7);
2005 PRINT "NEW TOTAL ELECTRICAL DEMAND CHARGE ($) = ";
2010 PRINT USING "#####.##"; DC2
2015 ANS$ = INPUT$(1)
2020 PRINT : PRINT TAB(7);
2025 IF DC1 = 0  AND DC2  0  THEN 2050
2030 PRINT "PRICE VARIATION OF CURRENT ELECTRICAL DEMAND
CHARGE (%) = ";
2035 PRINT USING "###.##"; R(3)
2040 IF DC2 = 0  THEN 2060
2045 PRINT TAB(7);
2050 PRINT "PRICE VARIATION OF NEW ELECTRICAL DEMAND
CHARGE (%) = ";
2055 PRINT USING "###.##"; R(4)
2060 ANS$ = INPUT$(1)
2065 CLS
2070 PRINT : PRINT : PRINT TAB(7);
2075 PRINT "DO YOU WISH TO REVIEW YOUR ANSWERS AGAIN
(Y/N)?  ";
2080 LINE INPUT "", ANS$
2085 IF ANS$ = "Y" OR ANS$ = "y"  THEN 1965
2090 IF ANS$ = "N" OR ANS$ = "n"  THEN 2100
2095 GOSUB 4350 : GOTO 2075
2100 PRINT : PRINT : PRINT TAB(7);
2105 PRINT "ARE ALL OF THE ANSWERS CORRECT (Y/N)?  ";
2110 LINE INPUT "", ANS$
```

```
CONSUMPTION AND FUEL COSTS."
2330 PRINT : PRINT : PRINT TAB(7);
2335 PRINT "DO YOU WISH TO CALCULATE TILLAGE COST (Y/N)?
";
2340 LINE INPUT "", ANS$
2345 IF ANS$ = "Y" OR ANS$ = "y"  THEN 2360
2350 IF ANS$ = "N" OR ANS$ = "n"  THEN 2770
2355 GOSUB 4350 : GOTO 2335
2360 N = 2
2365 IF VAR$(1) = "IRRIGATED AREA"  THEN SIZE = 1
2370 VAR$(1) = "FIELD SIZE"
2375 VAR$(2) = "FUEL CONSUMPTION"
2380 IF W = 1  THEN 2400
2385 UVAR$(1) = "(AC)"
2390 UVAR$(2) = "(GAL/AC)"
2395 GOTO 2410
2400 UVAR$(1) = "(HA)"
2405 UVAR$(2) = "(L/HA)"
2410 CLS
2415 PRINT : PRINT : PRINT TAB(7);
2420 PRINT "TYPE THE LETTER CORRESPONDING TO THE TYPE OF
FUEL CURRENTLY USED"
2425 PRINT TAB(7);
2430 PRINT "FOR TILLAGE OPERATIONS."
2435 PRINT : PRINT TAB(12);
2440 PRINT "D = DIESEL FUEL"
2445 PRINT TAB(12);
2450 PRINT "G = GASOLINE"
2455 LINE INPUT "", ANS$
2460 Z = 1
2465 CLS
2470 PRINT : PRINT : PRINT TAB(7);
2475 IF ANS$ = "D" OR ANS$ = "d"  THEN 2490
2480 IF ANS$ = "G" OR ANS$ = "g"  THEN 2500
2485 GOSUB 4350 : GOTO 2440
2490 VARIAB$(Z) = "DIESEL FUEL"
2495 GOTO 2505
2500 VARIAB$(Z) = "GASOLINE"
2505 IF W = 1  THEN 2520
2510 UVARIAB$(Z) = "(CENTS/GAL)"
2515 GOTO 2525
2520 UVARIAB$(Z) = "(CENTS/L)"
2525 IF Z = 2  THEN 2590
2530 PRINT "WILL THE ";VARYT$;" CHANGE (Y/N)?  ";
2535 LINE INPUT "", ANS$
2540 IF ANS$ = "Y" OR ANS$ = "y"  THEN 2555
2545 IF ANS$ = "N" OR ANS$ = "n"  THEN 2580
2550 GOSUB 4350 : GOTO 2530
2555 Z = 2
2560 CLS
```

```
2565 PRINT : PRINT : PRINT TAB(7);
2570 IF VARIAB$(1) = "DIESEL FUEL"  THEN 2500
2575 IF VARIAB$(1) = "GASOLINE"  THEN 2490
2580 UVARIAB$(2) = UVARIAB$(1)
2585 VARIAB$(2) = VARIAB$(1)
2590 GOSUB 4370
2595 CLS
2600 PRINT : PRINT : PRINT TAB(7);
2605 Z = 0
2610 Z = Z + 1
2615 PRINT "WHAT IS THE COST OF ";VARIAB$(Z);"
";UVARIAB$(Z);"?  ";
2620 INPUT "", COST(Z)
2625 GOSUB 4125
2630 IF VARIAB$(2) = VARIAB$(1)  THEN 2645
2635 IF Z = 2  THEN 2660
2640 GOTO 2610
2645 COST(2) = COST(1)
2650 R(2) = R(1)
2655 PVF(2) = PVF(1)
2660 GOSUB 4565
2665 CLS
2670 PRINT : PRINT : PRINT TAB(7);
2675 PRINT "DO YOU WISH TO REVIEW YOUR ANSWERS AGAIN
(Y/N)?  ";
2680 LINE INPUT "", ANS$
2685 IF ANS$ = "Y" OR ANS$ = "y"  THEN 2660
2690 IF ANS$ = "N" OR ANS$ = "n"  THEN 2700
2695 GOSUB 4350 : GOTO 2675
2700 PRINT : PRINT : PRINT TAB(7);
2705 PRINT "ARE ALL THE ANSWERS CORRECT (Y/N)?  ";
2710 LINE INPUT "", ANS$
2715 IF ANS$ = "Y" OR ANS$ = "y"  THEN 2730
2720 IF ANS$ = "N" OR ANS$ = "n"  THEN 2295
2725 GOSUB 4350 : GOTO 2705
2730 GOSUB 4775
2735 IF ANS$ = "N" OR ANS$ = "n"  THEN 2745
2740 LPRINT : LPRINT : LPRINT : LPRINT : LPRINT : LPRINT
2745 C1(SECNUM) = VAR1(1) * VAR1(2) * COST(1) / 100 *
PVF(1)
2750 C2(SECNUM) = VAR2(1) * VAR2(2) * COST(2) / 100 *
PVF(2)
2755 CD(SECNUM) = C1(SECNUM) - C2(SECNUM)
2760 PW(SECNUM) = CD(SECNUM) * AF
2765 GOSUB 4960
2770 SECNUM = 3
2775 SECNAME$(SECNUM) = "YIELD INCOME"
2780 VARYT$ = "CROP TYPE"
2785 GOSUB 4270
2790 PRINT "THIS SECTION ANALYZES THE INCOME GENERATED BY
```

```
THE CROP."
2795 PRINT : PRINT : PRINT TAB(7);
2800 PRINT "DO YOU WISH TO CALCULATE YIELD INCOME (Y/N)?
";
2805 LINE INPUT "", ANS$
2810 IF ANS$ = "Y" OR ANS$ = "y"  THEN 2825
2815 IF ANS$ = "N" OR ANS$ = "n"  THEN  3530
2820 GOSUB 4350 : GOTO 2800
2825 N = 1
2830 VAR$(1) = "FIELD SIZE"
2835 IF W = 1  THEN 2850
2840 UVAR$(1) = "(AC)"
2845 GOTO 2855
2850 UVAR$(1) = "(HA)"
2855 IF VAR$(1) = "IRRIGATED AREA"  THEN 2865
2860 GOSUB 4370
2865 CLS
2870 PRINT : PRINT : PRINT TAB(7);
2875 PRINT "WHAT CROP IS CURRENTLY GROWN?  ";
2880 LINE INPUT "", CROP1$
2885 PRINT : PRINT : PRINT TAB(7);
2890 PRINT "WHAT UNITS ARE USED TO MEASURE YIELD?  ";
2895 LINE INPUT "", UCROP1$
2900 PRINT : PRINT : PRINT TAB(7);
2905 IF W = 1  THEN 2925
2910 PRINT "WHAT IS THE CURRENT ";CROP1$;" YIELD
(";UCROP1$;"/AC)?  ";
2915 INPUT "", YIELD1
2920 GOTO 2935
2925 PRINT "WHAT IS THE CURRENT ";CROP1$;" YIELD
(";UCROP1$;"/HA)?  ";
2930 INPUT "", YIELD1
2935 CLS
2940 PRINT : PRINT : PRINT TAB(7);
2945 PRINT "WILL THE TYPE OF CROP CHANGE (Y/N)?  ";
2950 LINE INPUT "", ANS$
2955 IF ANS$ = "Y" OR ANS$ = "y"  THEN 2970
2960 IF ANS$ = "N" OR ANS$ = "n"  THEN 3010
2965 GOSUB 4350 : GOTO 2945
2970 CLS
2975 PRINT : PRINT : PRINT TAB(7);
2980 PRINT "WHAT WILL BE THE NEW CROP?  ";
2985 LINE INPUT "", CROP2$
2990 PRINT : PRINT : PRINT TAB(7);
2995 PRINT "WHAT WILL BE THE UNITS USED TO MEASURE YIELD?
";
3000 LINE INPUT "", UCROP2$
3005 GOTO 3020
3010 CROP2$ = CROP1$
3015 UCROP2$ = UCROP1$
```

```
3020 PRINT : PRINT : PRINT TAB(7);
3025 IF W = 1  THEN 3045
3030 PRINT "WHAT WILL BE THE NEW ";CROP2$;" YIELD
(";UCROP2$;"/AC)?  ";
3035 INPUT "", YIELD2
3040 GOTO 3055
3045 PRINT "WHAT WILL BE THE NEW ";CROP2$;" YIELD
(";UCROP2$;"/HA)?  ";
3050 INPUT ""; YIELD2
3055 CLS
3060 PRINT : PRINT : PRINT TAB(7);
3065 PRINT "WHAT IS THE COST OF ";CROP1$;"
($/";UCROP1$;")?  ";
3070 INPUT "", COST1
3075 Z = 1
3080 VARIAB$(Z) = CROP1$
3085 GOSUB 4125
3090 IF CROP2$ = CROP1$  THEN 3125
3095 PRINT "WHAT IS THE COST OF ";CROP2$;"
($/";UCROP2$;")?  ";
3100 INPUT "", COST2
3105 Z = 2
3110 VARIAB$(Z) = CROP2$
3115 GOSUB 4125
3120 GOTO 3145
3125 COST2 = COST1
3130 R(2) = R(1)
3135 PVF(2) = PVF(1)
3140 VARIAB$(2) = VARIAB$(1)
3145 GOSUB 4565
3150 IF W = 1  THEN 3190
3155 PRINT "CURRENT CROP YIELD (";UCROP1$;"/AC) = ";
3160 PRINT USING "#####.##"; YIELD1
3165 PRINT TAB(7);
3170 PRINT "NEW CROP YIELD (";UCROP2$;"/AC) = ";
3175 PRINT USING "#####.##"; YIELD2
3180 ANS$ = INPUT$(1) : PRINT : PRINT TAB(7);
3185 GOTO 3220
3190 PRINT "CURRENT CROP YIELD (";UCROP1$;"/HA) = ";
3195 PRINT USING "#####.##"; YIELD1
3200 PRINT TAB(7);
3205 PRINT "NEW CROP YIELD (";UCROP2$;"/HA) = ";
3210 PRINT USING "#####.##"; YIELD2
3215 ANS$ = INPUT$(1) : PRINT : PRINT TAB(7);
3220 PRINT CROP1$;" PRICE ($/";UCROP1$;") = ";
3225 PRINT USING "####.##"; COST1
3230 IF CROP2$ = CROP1$ THEN 3250
3235 PRINT TAB(7);
3240 PRINT CROP2$;" PRICE ($/";UCROP2$;") = ";
3245 PRINT USING "####.##"; COST2
```

```
3250 ANS$ = INPUT$(1) : PRINT : PRINT TAB(7);
3255 PRINT CROP1$;" PRICE VARIATION (%) = ";
3260 PRINT USING "###.##"; R(1)
3265 IF CROP2$ = CROP1$  THEN 3285
3270 PRINT TAB(7);
3275 PRINT CROP2$;" PRICE VARIATION (%) = ";
3280 PRINT USING "###.##"; R(2)
3285 ANS$ = INPUT$(1)
3290 CLS
3295 PRINT : PRINT : PRINT TAB(7);
3300 PRINT "DO YOU WISH TO REVIEW YOUR ANSWERS AGAIN (Y/N)
";
3305 LINE INPUT "", ANS$
3310 IF ANS$ = "Y" OR ANS$ = "y"  THEN 3145
3315 IF ANS$ = "N" OR ANS$ = "n"  THEN 3325
3320 GOSUB 4350 : GOTO 2675
3325 PRINT : PRINT : PRINT TAB(7);
3330 PRINT "ARE ALL THE ANSWERS CORRECT (Y/N)?  ";
3335 LINE INPUT "", ANS$
3340 IF ANS$ = "Y" OR ANS$ = "y"  THEN 3355
3345 IF ANS$ = "N" OR ANS$ = "n"  THEN 2770
3350 GOSUB 4350 : GOTO 3330
3355 GOSUB 4775
3360 IF ANS$ = "N" OR ANS$ = "n"  THEN 3505
3365 IF W = 1  THEN 3405
3370 LPRINT "CURRENT CROP YIELD (";UCROP1$;"/HA) = ";
3375 LPRINT USING "#####.##"; YIELD1
3380 LPRINT TAB(10);
3385 LPRINT "NEW CROP YIELD (";UCROP1$;"/HA) = ";
3390 LPRINT USING "#####.##"; YIELD2
3395 LPRINT : LPRINT TAB(10);
3400 GOTO 3435
3405 LPRINT "CURRENT CROP YIELD (";UCROP1$;"/HA) = ";
3410 LPRINT USING "#####.##"; YIELD1
3415 LPRINT TAB(10);
3420 LPRINT "NEW CROP YIELD (";UCROP2$;"/HA) = ";
3425 LPRINT USING "#####.##"; YIELD2
3430 LPRINT : LPRINT TAB(10);
3435 LPRINT CROP1$;" PRICE ($/";UCROP1$;") = ";
3440 LPRINT USING "####.##"; COST1
3445 IF CROP2$ = CROP1$  THEN 3465
3450 LPRINT TAB(10);
3455 LPRINT CROP2$;" PRICE ($/";UCROP2$;") = ";
3460 LPRINT USING "####.##"; COST2
3465 LPRINT : LPRINT TAB(10);
3470 LPRINT CROP1$;" PRICE VARIATION (%) = ";
3475 LPRINT USING "###.##"; R(1)
3480 IF CROP2$ = CROP1$  THEN 3500
3485 LPRINT TAB(10);
3490 LPRINT CROP2$; " PRICE VARIATION (%) = ";
```

```
3495 LPRINT USING "###.##"; R(2)
3500 LPRINT : LPRINT : LPRINT : LPRINT : LPRINT : LPRINT
3505 C1(SECNUM) = VAR1(1) * YIELD1 * COST1 * PVF(1)
3510 C2(SECNUM) = VAR2(1) * YIELD2 * COST2 * PVF(2)
3515 CD(SECNUM) = C2(SECNUM) - C1(SECNUM)
3520 PW(SECNUM) = CD(SECNUM) * AF
3525 GOSUB 4960
3530 CLS
3535 PRINT : PRINT : PRINT TAB(7);
3540 PRINT "YOU WILL NOW BE ALLOWED TO REVIEW THE FINAL
RESULTS.  RESULTS"
3545 PRINT TAB(7);
3550 PRINT "FROM THE VARIOUS SECTIONS WILL BE DISPLAYED
ONE SET AT A TIME."
3555 PRINT TAB(7);
3560 PRINT "HITTING ANY KEY WILL CAUSE THE NEXT SET TO BE
DISPLAYED.  A"
3565 PRINT TAB(7);
3570 PRINT "FINAL OVERALL ANALYSIS WILL ALSO BE
PRESENTED."
3575 PRINT : PRINT : PRINT
3580 FOR Z = 1 TO 3
3585   IF C1(Z) = 0 AND C2(Z) = 0  THEN 3690
3590   PRINT TAB(7);
3595   PRINT SECNAME$(Z);" RESULTS"
3600   PRINT : PRINT TAB(12);
3605   PRINT "CURRENT UNIFORM ANNUAL ";SECNAME$(Z);" ($) =
";
3610   PRINT USING "######.##"; C1(Z)
3615   PRINT TAB(12);
3620   PRINT "NEW UNIFORM ANNUAL ";SECNAME$(Z);" ($) = ";
3625   PRINT USING "######.##"; C2(Z)
3630   PRINT TAB(12);
3635   PRINT "UNIFORM ANNUAL ";SECNAME$(Z);" DIFFERENCE
($) = ";
3640   PRINT USING "######.##"; CD(Z)
3645   PRINT TAB(12);
3650   PRINT "PRESENT WORTH OF ANNUAL COST DIFFERENCE ($)
= ";
3655   PRINT USING "######.##"; PW(Z)
3660   ANS$ = INPUT$(1)
3665   PRINT : PRINT
3670   TOTC1 = TOTC1 + C1(Z)
3675   TOTC2 = TOTC2 + C2(Z)
3680   TOTCD = TOTCD + CD(Z)
3685   TOTPW = TOTPW + PW(Z)
3690 NEXT Z
3695 CLS
3700 PRINT : PRINT : PRINT TAB(23);
3705 PRINT "OVERALL FINAL RESULTS"
```

```
3710 PRINT : PRINT : PRINT : PRINT TAB(7);
3715 PRINT "INTEREST RATE (%) = ";
3720 PRINT USING "##.##"; I
3725 PRINT : PRINT TAB(7);
3730 PRINT "PERIOD OF ANALYSIS (YEARS) = ";
3735 PRINT USING "##.##"; Y
3740 PRINT : PRINT : PRINT TAB(7);
3745 PRINT "TOTAL CURRENT UNIFORM ANNUAL COST ($) = ";
3750 PRINT USING "#######.##"; TOTC1
3755 PRINT : PRINT TAB(7);
3760 PRINT "TOTAL NEW UNIFORM ANNUAL COST ($) = ";
3765 PRINT USING "#######.##"; TOTC2
3770 PRINT : PRINT TAB(7);
3775 PRINT "TOTAL UNIFORM ANNUAL COST DIFFERENCE ($) = ";
3780 PRINT USING "#######.##"; TOTCD
3785 PRINT : PRINT TAB(7);
3790 PRINT "TOTAL PRESENT WORTH OF ANNUAL COST DIFFERENCES
($) = ";
3795 PRINT USING "#######.##"; TOTPW
3800 ANS$ = INPUT$(1)
3805 CLS
3810 PRINT : PRINT : PRINT TAB(7);
3815 PRINT "DO YOU WISH TO REVIEW THE FINAL RESULTS AGAIN
(Y/N)?  ";
3820 LINE INPUT "", ANS$
3825 IF ANS$ = "Y" OR ANS$ = "y"  THEN 3530
3830 IF ANS$ = "N" OR ANS$ = "n"  THEN 3840
3835 GOSUB 4350 : GOTO 3815
3840 CLS
3845 PRINT : PRINT : PRINT TAB(7);
3850 PRINT "DO YOU WANT A COPY OF THE FINAL RESULTS (Y/N)?
";
3855 LINE INPUT "", ANS$
3860 IF ANS$ = "Y" OR ANS$ = "y"  THEN 3875
3865 IF ANS$ = "N" OR ANS$ = "n"  THEN 4080
3870 GOSUB 4350 : GOTO 3850
3875 LPRINT TAB(28);
3880 LPRINT "FINAL RESULTS"
3885 LPRINT : LPRINT : LPRINT
3890 FOR Z = 1 TO 3
3895   IF C1(Z) = 0 AND C2(Z) = 0  THEN 3970
3900   LPRINT : LPRINT : LPRINT TAB(7);
3905   LPRINT SECNAME$(Z);" RESULTS"
3910   LPRINT : LPRINT TAB(10);
3915   LPRINT "CURRENT UNIFORM ANNUAL ";SECNAME$(Z);" ($)
= ";
3920   LPRINT USING "######.##"; C1(Z)
3925   LPRINT TAB(10);
3930   LPRINT "NEW UNIFORM ANNUAL ";SECNAME$(Z);" ($) = ";
3935   LPRINT USING "######.##"; C2(Z)
```

```
3940   LPRINT TAB(10);
3945   LPRINT "UNIFORM ANNUAL ";SECNAME$(Z);" DIFFERENCE
($) = ";
3950   LPRINT USING "######.##"; CD(Z)
3955   LPRINT TAB(10);
3960   LPRINT "PRESENT WORTH OF ANNUAL COST DIFFERENCE ($)
= ";
3965   LPRINT USING "######.##"; PW(Z)
3970 NEXT Z
3975 LPRINT : LPRINT : LPRINT : LPRINT : LPRINT
3980 LPRINT TAB(25);
3985 LPRINT "OVERALL FINAL RESULTS"
3990 LPRINT : LPRINT : LPRINT : LPRINT TAB(10);
3995 LPRINT "INTEREST RATE (%) = ";
4000 LPRINT USING "##.##"; I
4005 LPRINT : LPRINT TAB(10);
4010 LPRINT "PERIOD OF ANALYSIS (YEARS) = ";
4015 LPRINT USING "##.##"; Y
4020 LPRINT : LPRINT : LPRINT TAB(10);
4025 LPRINT "TOTAL CURRENT UNIFORM ANNUAL COST ($) = ";
4030 LPRINT USING "######.##"; TOTC1
4035 LPRINT : LPRINT TAB(10);
4040 LPRINT "TOTAL NEW UNIFORM ANNUAL COST ($) = ";
4045 LPRINT USING "######.##"; TOTC2
4050 LPRINT : LPRINT TAB(10);
4055 LPRINT "TOTAL UNIFORM ANNUAL COST DIFFERENCE ($) = ";
4060 LPRINT USING "######.##"; TOTCD
4065 LPRINT : LPRINT TAB(10);
4070 LPRINT "TOTAL PRESENT WORTH OF ANNUAL COST
DIFFERENCES ($) = ";
4075 LPRINT USING "######.##"; TOTPW
4080 CLS
4085 PRINT : PRINT : PRINT TAB(7);
4090 PRINT "DO YOU WANT TO RUN THE PROGRAM AGAIN (Y/N)?
";
4095 LINE INPUT "", ANS$
4100 IF ANS$ = "Y" OR ANS$ = "y"  THEN 4115
4105 IF ANS$ = "N" OR ANS$ = "n"  THEN 4120
4110 GOSUB 4350 : GOTO 4090
4115 GOTO 1185
4120 END
4125 CLS
4130 PRINT : PRINT : PRINT TAB(7);
4135 PRINT "YOU HAVE THE OPTION OF ACCOUNTING FOR
";VARIAB$(Z)
4140 PRINT TAB(7);
4145 PRINT "PRICE VARIATIONS OVER THE PERIOD OF ANALYSIS."
4150 PRINT : PRINT : PRINT TAB(7);
4155 PRINT "DO YOU WISH TO ACCOUNT FOR A PRICE VARIATION
(Y/N)?  ";
```

```
4160 LINE INPUT "", ANS$
4165 IF ANS$ = "N" OR ANS$ = "n"  THEN 4250
4170 IF ANS$ = "Y" OR ANS$ = "y"  THEN 4180
4175 GOSUB 4350 : GOTO 4155
4180 PRINT : PRINT : PRINT TAB(7);
4185 PRINT "PRICE VARIATION CANNOT EQUAL INTEREST RATE"
4190 PRINT : PRINT : PRINT TAB(7);
4195 PRINT "WHAT VARIATION DO YOU EXPECT (%)?  ";
4200 INPUT "", R(Z)
4205 IF R(Z) = I  THEN 4215
4210 GOTO 4230
4215 PRINT : PRINT : PRINT TAB(7);
4220 PRINT "PRICE VARIATION CANNOT EQUAL INTEREST RATE.
INTEREST RATE = ";I
4225 GOTO 4190
4230 PVF1 =
((1+R(Z)/100)^Y-(1+I/100)^Y)/((1+R(Z)/100)-(1+I/100))
4235 PVF2 = (I/100) / ((1+I/100)^Y - 1)
4240 PVF(Z) = PVF1 * PVF2
4245 GOTO 4255
4250 PVF(Z) = 1  : R(Z) = 0
4255 CLS
4260 PRINT : PRINT : PRINT TAB(7);
4265 RETURN
4270 CLS
4275 PRINT : PRINT : PRINT : PRINT TAB(25);
4280 PRINT "SECTION ";SECNUM;".  ";SECNAME$(SECNUM)
4285 PRINT : PRINT : PRINT : PRINT TAB(7);
4290 RETURN
4295 CLS
4300 PRINT : PRINT : PRINT TAB(7);
4305 PRINT "YOU HAVE THE OPTION OF WORKING IN METRIC OR
ENGLISH UNITS."
4310 PRINT : PRINT TAB(7);
4315 PRINT "TYPE M FOR METRIC OR E FOR ENGLISH.  ";
4320 LINE INPUT "", ANS$
4325 IF ANS$ = "M" OR ANS$ = "m"  THEN W = 1
4330 IF ANS$ = "E" OR ANS$ = "e"  THEN W = 2
4335 IF W = 1 OR W = 2  THEN 4345
4340 GOSUB 4350 : GOTO 4305
4345 RETURN
4350 PRINT : PRINT : PRINT TAB(7);
4355 PRINT "YOU DID NOT TYPE ONE OF THE GIVEN LETTERS.
PLEASE TRY AGAIN."
4360 PRINT : PRINT : PRINT TAB(7);
4365 RETURN
4370 FOR Z = 1 TO N
4375   IF SIZE = 1 AND SECNAME$(3) = "YIELD INCOME"  THEN
4555
4380   IF SIZE = 1  THEN Z = 2
```

```
4385    CLS
4390    PRINT :PRINT : PRINT TAB(7);
4395    IF VAR$(Z) = "FRICTION AND MINOR LOSS"  THEN 4405
4400    GOTO 4410
4405    GOSUB 5205
4410    IF VAR$(Z) = "SYSTEM PRESSURE"  THEN 4420
4415    GOTO 4425
4420    GOSUB 5255
4425    IF VAR$(Z) = "SPRAY LOSS"  THEN 4435
4430    GOTO 4440
4435    GOSUB 5280
4440    IF X = 1  THEN Z = 10
4445    IF X = 2 AND Z = 10  THEN 4545
4450    IF SECNUM = 2 AND VAR$(Z) = "FUEL CONSUMPTION"
THEN 4460
4455    GOTO 4475
4460    GOSUB 5450
4465    CLS
4470    PRINT : PRINT : PRINT TAB(7);
4475    PRINT "WHAT IS THE CURRENT ";VAR$(Z);"
";UVAR$(Z);"?  ";
4480    INPUT "", VAR1(Z)
4485    PRINT : PRINT : PRINT TAB(7);
4490    PRINT "WILL THE ";VAR$(Z);" CHANGE (Y/N)?  ";
4495    LINE INPUT "", ANS$
4500    PRINT : PRINT : PRINT TAB(7);
4505    IF ANS$ = "Y" OR ANS$ = "y"  THEN 4520
4510    IF ANS$ = "N" OR ANS$ = "n"  THEN 4535
4515    GOSUB 4350 : GOTO 4490
4520    PRINT "WHAT WILL BE THE NEW ";VAR$(Z);"
";UVAR$(Z)"?  ";
4525    INPUT "", VAR2(Z)
4530    GOTO 4555
4535    VAR2(Z) = VAR1(Z)
4540    GOTO 4555
4545    VAR1(10) = 100 - VAR1(7) - VAR1(8) - VAR1(9)
4550    VAR2(10) = 100 - VAR2(7) - VAR2(8) - VAR2(9)
4555 NEXT Z
4560 RETURN
4565 CLS
4570 PRINT : PRINT : PRINT TAB(7);
4575 PRINT "YOU WILL NOW BE ALLOWED TO REVIEW YOUR ANSWERS
TO THE PREVIOUS"
4580 PRINT TAB(7);
4585 PRINT "QUESTIONS CONCERNING ";SECNAME$(SECNUM);"."
4590 PRINT : PRINT TAB(7);
4595 PRINT "VARIABLE VALUES WILL BE DISPLAYED ONE SET AT A
TIME.  HITTING ANY"
4600 PRINT TAB(7);
4605 PRINT "KEY WILL CAUSE THE NEXT SET TO BE DISPLAYED.
```

```
YOU WILL HAVE AN"
4610 PRINT TAB(7);
4615 PRINT "OPPORTUNITY TO CORRECT ANY ANSWERS AFTER ALL
THE VALUES HAVE BEEN"
4620 PRINT TAB(7);
4625 PRINT "VIEWED."
4630 PRINT : PRINT : PRINT TAB(7);
4635 FOR Z = 1 TO N
4640   IF Z = 6 AND X = 1  THEN Z = 10
4645   PRINT "CURRENT ";VAR$(Z);" ";UVAR$(Z);" = ";
4650   PRINT USING "####.##"; VAR1(Z)
4655   PRINT TAB(7);
4660   PRINT "NEW ";VAR$(Z);" ";UVAR$(Z);" = ";
4665   PRINT USING "####.##"; VAR2(Z)
4670   ANS$ = INPUT$(1)  : PRINT : PRINT TAB(7);
4675 NEXT Z
4680 PRINT "CURRENT ";VARYT$;" = "; VARIAB$(1)
4685 PRINT TAB(7);
4690 PRINT "NEW ";VARYT$;" = "; VARIAB$(2)
4695 ANS$ = INPUT$(1)  : PRINT : PRINT TAB(7);
4700 IF SECNAME$(3) = "YIELD INCOME"  THEN 4770
4705 PRINT "CURRENT ";VARYC$;" ";UVARIAB$(1);" = ";
4710 PRINT USING "####.##"; COST(1)
4715 PRINT TAB(7);
4720 PRINT "NEW ";VARYC$;" ";UVARIAB$(2);" = ";
4725 PRINT USING "####.##"; COST(2)
4730 ANS$ = INPUT$(1)  : PRINT : PRINT TAB(7);
4735 PRINT VARIAB$(1);" PRICE VARIATION (%) = ";
4740 PRINT USING "###.##"; R(1)
4745 IF VARIAB$(2) = VARIAB$(1)  THEN 4765
4750 PRINT TAB(7);
4755 PRINT VARIAB$(2);" PRICE VARIATION (%) = ";
4760 PRINT USING "###.##"; R(2)
4765 ANS$ = INPUT$(1)
4770 RETURN
4775 CLS
4780 PRINT : PRINT : PRINT TAB(7);
4785 PRINT "DO YOU WANT A COPY OF THE ";SECNAME$(SECNUM);"
VARIABLES (Y/N)?  ";
4790 LINE INPUT "", ANS$
4795 IF ANS$ = "Y" OR ANS$ = "y"  THEN 4810
4800 IF ANS$ = "N" OR ANS$ = "n"  THEN 4955
4805 GOSUB 4350 : GOTO 4785
4810 LPRINT TAB(25);
4815 LPRINT "SUMMARY OF ";SECNAME$(SECNUM);" VARIABLES"
4820 LPRINT : LPRINT : LPRINT : LPRINT TAB(10);
4825 FOR Z = 1 TO N
4830   IF Z = 6 AND X = 1  THEN Z = 10
4835   LPRINT "CURRENT ";VAR$(Z);" ";UVAR$(Z);" = ";
4840   LPRINT USING "####.##"; VAR1(Z)
```

```
4845   LPRINT TAB(10);
4850   LPRINT "NEW ";VAR$(Z);" ";UVAR$(Z);" = ";
4855   LPRINT USING "####.##"; VAR2(Z)
4860   LPRINT : LPRINT TAB(10);
4865 NEXT Z
4870 LPRINT "CURRENT ";VARYT$;" = "; VARIAB$(1)
4875 LPRINT TAB(10);
4880 LPRINT "NEW ";VARYT$;" = "; VARIAB$(2)
4885 LPRINT : LPRINT TAB(10);
4890 IF SECNAME$(3) = "YIELD INCOME"  THEN 4955
4895 LPRINT "CURRENT ";VARYC$;" ";UVARIAB$(1);" = ";
4900 LPRINT USING "####.##"; COST(1)
4905 LPRINT TAB(10);
4910 LPRINT "NEW ";VARYC$;" ";UVARIAB$(2);" = ";
4915 LPRINT USING "####.##"; COST(2)
4920 LPRINT : LPRINT TAB(10);
4925 LPRINT VARIAB$(1); " PRICE VARIATION (%) = ";
4930 LPRINT USING "###.##"; R(1)
4935 IF VARIAB$(2) = VARIAB$(1)  THEN 4955
4940 LPRINT TAB(10);
4945 LPRINT VARIAB$(2); " PRICE VARIATION (%) = ";
4950 LPRINT USING "###.##"; R(2)
4955 RETURN
4960 CLS
4965 PRINT : PRINT : PRINT TAB(22);
4970 PRINT SECNAME$(SECNUM);" RESULTS"
4975 PRINT : PRINT : PRINT : PRINT TAB(7);
4980 PRINT "INTEREST RATE (%) = ";
4985 PRINT USING "##.##"; I
4990 PRINT : PRINT TAB(7);
4995 PRINT "PERIOD OF ANALYSIS (YEARS) = ";
5000 PRINT USING "##.##"; Y
5005 PRINT : PRINT : PRINT TAB(7);
5010 PRINT "CURRENT UNIFORM ANNUAL ";SECNAME$(SECNUM);"
($) = ";
5015 PRINT USING "######.##"; C1(SECNUM)
5020 PRINT : PRINT TAB(7);
5025 PRINT "NEW UNIFORM ANNUAL ";SECNAME$(SECNUM);" ($) =
";
5030 PRINT USING "######.##"; C2(SECNUM)
5035 PRINT : PRINT TAB(7);
5040 PRINT "UNIFORM ANNUAL ";SECNAME$(SECNUM);" DIFFERENCE
($) = ";
5045 PRINT USING "######.##"; CD(SECNUM)
5050 PRINT : PRINT TAB(7);
5055 PRINT "PRESENT WORTH OF ANNUAL COST DIFFERENCE ($) =
";
5060 PRINT USING "######.##"; PW(SECNUM)
5065 PRINT : PRINT : PRINT : PRINT : PRINT TAB(7);
5070 PRINT "DO YOU WANT A COPY OF THE ";SECNAME$(SECNUM);"
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```
RESULTS (Y/N)?  ";
5075 LINE INPUT "", ANS$
5080 IF ANS$ = "Y" OR ANS$ = "y"  THEN 5095
5085 IF ANS$ = "N" OR ANS$ = "n"  THEN 5200
5090 GOSUB 4350 : GOTO 5070
5095 LPRINT TAB(25);
5100 LPRINT SECNAME$(SECNUM);" RESULTS"
5105 LPRINT : LPRINT : LPRINT : LPRINT TAB(10);
5110 LPRINT "INTEREST RATE (%) = ";
5115 LPRINT USING "##.##"; I
5120 LPRINT : LPRINT TAB(10);
5125 LPRINT "PERIOD OF ANALYSIS (YEARS) = ";
5130 LPRINT USING "##.##"; Y
5135 LPRINT : LPRINT : LPRINT TAB(10);
5140 LPRINT "CURRENT UNIFORM ANNUAL ";SECNAME$(SECNUM);"
($) = ";
5145 LPRINT USING "######.##"; C1(SECNUM)
5150 LPRINT : LPRINT TAB(10);
5155 LPRINT "NEW UNIFORM ANNUAL ";SECNAME$(SECNUM);" ($) =
";
5160 LPRINT USING "######.##"; C2(SECNUM)
5165 LPRINT : LPRINT TAB(10);
5170 LPRINT "UNIFORM ANNUAL ";SECNAME$(SECNUM);"
DIFFERENCE ($) = ";
5175 LPRINT USING "######.##"; CD(SECNUM)
5180 LPRINT : LPRINT TAB(10);
5185 LPRINT "PRESENT WORTH OF ANNUAL COST DIFFERENCE ($) =
";
5190 LPRINT USING "######.##"; PW(SECNUM)
5195 LPRINT CHR$(12)
5200 RETURN
5205 PRINT "FRICTION AND MINOR LOSSES IN PIPELINES BETWEEN
THE WATER SOURCE"
5210 PRINT TAB(7);
5215 PRINT "AND IRRIGATION SYSTEM CAN BE APPROXIMATED
USING THE FOLLOWING:"
5220 PRINT : PRINT TAB(7);
5225 IF W = 1  THEN 5240
5230 PRINT "0.06 FOOT OF FRICTION AND MINOR LOSS FOR EVERY
FOOT OF PIPE"
5235 GOTO 5245
5240 PRINT "0.06 METER OF FRICTION AND MINOR LOSS FOR
EVERY METER OF PIPE"
5245 PRINT : PRINT : PRINT TAB(7);
5250 RETURN
5255 PRINT "SYSTEM PRESSURE IS THE SUM OF SPRINKLER
OPERATING PRESSURE AND"
5260 PRINT TAB(7);
5265 PRINT "PRESSURE LOSS IN THE IRRIGATION SYSTEM."
5270 PRINT : PRINT : PRINT TAB(7);
```

```
5275 RETURN
5280 PRINT "IRRIGATION EFFICIENCY IS THE PERCENT OF WATER
LEAVING THE SYSTEM"
5285 PRINT TAB(7);
5290 PRINT "THAT CAN BE USED BY THE CROP.  IRRIGATION
EFFICIENCY IS EQUAL TO"
5295 PRINT TAB(7);
5300 PRINT "100 - SPRAY LOSS - RUNOFF - DEEP PERCOLATION.
SPRAY LOSS IS THE"
5305 PRINT TAB(7);
5310 PRINT "PERCENTAGE OF WATER LEAVING THE IRRIGATION
SYSTEM THAT FAILS TO"
5315 PRINT TAB(7);
5320 PRINT "REACH THE CROP CANOPY, RUNOFF IS THE
PERCENTAGE OF WATER REACHING"
5325 PRINT TAB(7);
5330 PRINT "THE CROP CANOPY THAT FAILS TO INFILTRATE THE
SOIL, AND DEEP"
5335 PRINT TAB(7);
5340 PRINT "PERCOLATION IS THE PERCENTAGE OF WATER
INFILTRATING THE SOIL THAT"
5345 PRINT TAB(7);
5350 PRINT "MOVES BELOW THE ROOT ZONE."
5355 PRINT : PRINT : PRINT TAB(7);
5360 PRINT "YOU HAVE THE OPTION OF ENTERING AN OVERALL
VALUE FOR IRRIGATION"
5365 PRINT TAB(7);
5370 PRINT "EFFICIENCY OR ENTERING SEPERATE VALUES FOR
SPRAY LOSS, RUNOFF AND"
5375 PRINT TAB(7);
5380 PRINT "DEEP PERCOLATION."
5385 PRINT : PRINT : PRINT TAB(7);
5390 PRINT "TYPE A 1 IF YOU WISH TO ENTER AN OVERALL VALUE
OR A 2 IF YOU WISH"
5395 PRINT TAB(7);
5400 PRINT "TO ENTER SEPERATE SPRAY LOSS, RUNOFF AND DEEP
PERCOLATION VALUES."
5405 LINE INPUT "", ANS$
5410 CLS
5415 PRINT : PRINT : PRINT TAB(7);
5420 IF ANS$ = "1"  THEN  X = 1
5425 IF ANS$ = "2"  THEN  X = 2
5430 IF ANS$ = "1" OR ANS$ = "2"  THEN 5445
5435 PRINT "YOU DID NOT TYPE A 1 OR A 2.  PLEASE TRY
AGAIN."
5440 GOTO 5385
5445 RETURN
5450 PRINT "A TABLE IS AVAILABLE TO HELP YOU ESTIMATE FUEL
CONSUMPTION FOR"
5455 PRINT TAB(7);
```

```
5460 PRINT "VARIOUS TILLAGE OPERATIONS.  VALUES OF DIESEL
FUEL CONSUMPTION"
5465 PRINT TAB(7);
5470 PRINT "PER UNIT AREA FOR LOW, MEDIUM AND HIGH DRAFT
SOILS ARE GIVEN."
5475 PRINT TAB(7);
5480 PRINT "A GASOLINE EQUIVALENT CAN BE CALCULATED BY
MULTIPLYING THESE"
5485 PRINT TAB(7);
5490 PRINT "VALUES BY 1.4."
5495 PRINT : PRINT : PRINT TAB(7);
5500 PRINT "DO YOU WANT A COPY OF THIS TABLE PRINTED
(Y/N)?  ";
5505 ANS$ = INPUT$(1)
5510 IF ANS$ = "Y" OR ANS$ = "y"  THEN 5525
5515 IF ANS$ = "N" OR ANS$ = "n"  THEN 5545
5520 GOSUB 4350 : GOTO 5500
5525 IF W = 1  THEN 5540
5530 GOSUB 5555
5535 GOTO 5550
5540 GOSUB 6005
5545 PRINT : PRINT : PRINT TAB(7);
5550 RETURN
5555 LPRINT TAB(13);
5560 LPRINT "DIESEL FUEL REQUIREMENTS FOR VARIOUS FIELD
OPERATIONS"
5565 LPRINT : LPRINT : LPRINT : LPRINT TAB(10);
5570 LPRINT
"-----------------------------------------------------------
--"
5575 LPRINT TAB(48);
5580 LPRINT "SOIL DRAFT RATINGS"
5585 LPRINT TAB(21);
5590 LPRINT "OPERATIONS                    Low     Moderate
High"
5595 LPRINT TAB(10);
5600 LPRINT
"-----------------------------------------------------------
--"
5605 LPRINT TAB(43);
5610 LPRINT "fuel requirements (gal/ac)"
5615 LPRINT : LPRINT TAB(10);
5620 LPRINT "Shredding cornstalks                  0.75
0.75       0.75"
5625 LPRINT TAB(10);
5630 LPRINT "Subsoil chiseling, 14 in              1.30
2.10       2.95"
5635 LPRINT TAB(10);
5640 LPRINT "Moldboard plowing, 8 in               1.15
1.85       2.60"
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5645 LPRINT TAB(10);
5650 LPRINT "Chiseling, 8 in                          0.75
1.25        1.75"
5655 LPRINT TAB(10);
5660 LPRINT "Offset disking                           0.60
0.95        1.35"
5665 LPRINT TAB(10);
5670 LPRINT "Field cultivating, plowed ground         0.55
0.60        0.65"
5675 LPRINT TAB(10);
5680 LPRINT "Tandem disking, plowed ground            0.50
0.55        0.60"
5685 LPRINT TAB(10);
5690 LPRINT "Tandem disking, 2nd trip                 0.45
0.50        0.55"
5695 LPRINT TAB(10);
5700 LPRINT "Tandem disking, cornstalks               0.40
0.45        0.50"
5705 LPRINT TAB(10);
5710 LPRINT "Forming ridges, fall                     0.40
0.45        0.50"
5715 LPRINT TAB(10);
5720 LPRINT "Harrowing, spring tooth                  0.35
0.40        0.45"
5725 LPRINT TAB(10);
5730 LPRINT "Harrowing, spike tooth                   0.35
0.35        0.35"
5735 LPRINT TAB(10);
5740 LPRINT "Field cultivating + planter              0.95
1.05        1.15"
5745 LPRINT TAB(10);
5750 LPRINT "NH3 application, plowed ground           0.60
0.70        0.80"
5755 LPRINT TAB(10);
5760 LPRINT "Strip rotary till + planter              0.85
0.95        1.05"
5765 LPRINT TAB(10);
5770 LPRINT "Planting, wheel track                    0.60
0.65        0.70"
5775 LPRINT TAB(10);
5780 LPRINT "Planting, conventional                   0.40
0.50        0.60"
5785 LPRINT TAB(10);
5790 LPRINT "Planting, till                           0.40
0.50        0.60"
5795 LPRINT TAB(10);
5800 LPRINT "Planting, no-till                        0.40
0.50        0.60"
5805 LPRINT TAB(10);
5810 LPRINT "Cultivating, disk hiller                 0.35
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```
0.40        0.45"
5815 LPRINT TAB(10);
5820 LPRINT "Cultivating, sweeps                    0.30
0.35        0.40"
5825 LPRINT TAB(10);
5830 LPRINT "Cultivating, rolling tines             0.30
0.35        0.40"
5835 LPRINT TAB(10);
5840 LPRINT "Rotary hoeing                          0.25
0.25        0.25"
5845 LPRINT TAB(10);
5850 LPRINT "Spraying fertilizer                    0.20
0.20        0.20"
5855 LPRINT TAB(10);
5860 LPRINT "Spraying pesticide                     0.15
0.15        0.15"
5865 LPRINT TAB(10);
5870 LPRINT
"--------------------------------------------------------------
--"
5875 LPRINT : LPRINT : LPRINT TAB(10);
5880 LPRINT "To convert diesel to gasoline equivalent,
multiply by 1.4."
5885 LPRINT : LPRINT TAB(10);
5890 LPRINT "Fuel requirements given are averages of tests
conducted over"
5895 LPRINT TAB(10);
5900 LPRINT "a wide range of soils.  The actual fuel
requirement for a"
5905 LPRINT TAB(10);
5910 LPRINT "particular field operation in a particular
soil type may vary"
5915 LPRINT TAB(10);
5920 LPRINT "as much as 25 percent or more from the value
given.  Soil"
5925 LPRINT TAB(10);
5930 LPRINT "types associated with the draft ratings
include:  Low = sands"
5935 LPRINT TAB(10);
5940 LPRINT "and sandy loams; Moderate = loams and silt
loams; High = clay"
5945 LPRINT TAB(10);
5950 LPRINT "loams and clays."
5955 LPRINT : LPRINT TAB(10);
5960 LPRINT "The reference for the preceeding table is:
Griffith, D.R. and"
5965 LPRINT TAB(10);
5970 LPRINT "S.D. Parsons.  1981.  Energy requirements for
tillage planting"
5975 LPRINT TAB(10);
```

```
5980 LPRINT "systems.  Proceedings, ASAE Conference on
Crop Production with"
5985 LPRINT TAB(10);
5990 LPRINT "Conservation in the 80's, ASAE, St. Joseph,
MI.  49085."
5995 LPRINT CHR$(12)
6000 RETURN
6005 LPRINT TAB(13);
6010 LPRINT "DIESEL FUEL REQUIREMENTS FOR VARIOUS FIELD
OPERATIONS"
6015 LPRINT : LPRINT : LPRINT : LPRINT TAB(10);
6020 LPRINT
"-------------------------------------------------------
--"
6025 LPRINT TAB(48);
6030 LPRINT "SOIL DRAFT RATINGS"
6035 LPRINT TAB(21);
6040 LPRINT "OPERATIONS                    Low     Moderate
High"
6045 LPRINT TAB(10);
6050 LPRINT
"-------------------------------------------------------
--"
6055 LPRINT TAB(45);
6060 LPRINT "fuel requirements (L/ha)"
6065 LPRINT : LPRINT TAB(10);
6070 LPRINT "Shredding cornstalks                      7.02
7.02     7.02"
6075 LPRINT TAB(10);
6080 LPRINT "Subsoil chiseling, 35.6 cm               12.16
19.64     27.59"
6085 LPRINT TAB(10);
6090 LPRINT "Moldboard plowing, 20.3 cm               10.76
17.30     24.32"
6095 LPRINT TAB(10);
6100 LPRINT "Chiseling, 20.3 cm                        7.02
11.69     16.37"
6105 LPRINT TAB(10);
6110 LPRINT "Offset disking                            5.61
8.89     12.63"
6115 LPRINT TAB(10);
6120 LPRINT "Field cultivating, plowed ground          5.14
5.61     6.08"
6125 LPRINT TAB(10);
6130 LPRINT "Tandem disking, plowed ground             4.68
5.14     5.61"
6135 LPRINT TAB(10);
6140 LPRINT "Tandem disking, 2nd trip                  4.21
4.68     5.14"
6145 LPRINT TAB(10);
```

```
6150 LPRINT "Tandem disking, cornstalks             3.74
4.21      4.68"
6155 LPRINT TAB(10);
6160 LPRINT "Forming ridges, fall                   3.74
4.21      4.68"
6165 LPRINT TAB(10);
6170 LPRINT "Harrowing, spring tooth                3.27
3.74      4.21"
6175 LPRINT TAB(10);
6180 LPRINT "Harrowing, spike tooth                 3.27
3.27      3.27"
6185 LPRINT TAB(10);
6190 LPRINT "Field cultivating + planter            8.89
9.82     10.76"
6195 LPRINT TAB(10);
6200 LPRINT "NH3 application, plowed ground         5.61
6.55      7.48"
6205 LPRINT TAB(10);
6210 LPRINT "Strip rotary till + planter            7.95
8.89      9.82"
6215 LPRINT TAB(10);
6220 LPRINT "Planting, wheel track                  5.61
6.08      6.55"
6225 LPRINT TAB(10);
6230 LPRINT "Planting, conventional                 3.74
4.68      5.61"
6235 LPRINT TAB(10);
6240 LPRINT "Planting, till                         3.74
4.68      5.61"
6245 LPRINT TAB(10);
6250 LPRINT "Planting, no-till                      3.74
4.68      5.61"
6255 LPRINT TAB(10);
6260 LPRINT "Cultivating, disk hiller               3.27
3.74      4.21"
6265 LPRINT TAB(10);
6270 LPRINT "Cultivating, sweeps                    2.81
3.27      3.74"
6275 LPRINT TAB(10);
6280 LPRINT "Cultivating, rolling tines             2.81
3.27      3.74"
6285 LPRINT TAB(10);
6290 LPRINT "Rotary hoeing                          2.34
2.34      2.34"
6295 LPRINT TAB(10);
6300 LPRINT "Spraying fertilizer                    1.87
1.87      1.87"
6305 LPRINT TAB(10);
6310 LPRINT "Spraying pesticide                     1.40
1.40      1.40"
```

```
6315 LPRINT TAB(10);
6320 LPRINT
"------------------------------------------------------------
--"
6325 LPRINT : LPRINT : LPRINT TAB(10);
6330 LPRINT "To convert diesel to gasoline equivalent,
multiply by 1.4."
6335 LPRINT : LPRINT TAB(10);
6340 LPRINT "Fuel requirements given are averages of tests
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Crop Production with"
6435 LPRINT TAB(10);
6440 LPRINT "Conservation in the 80's, ASAE, St. Joseph,
MI.  49085."
6445 LPRINT CHR$(12)
6450 RETURN
```